COTTON IN INDIA

A MONOGRAPH

GOSSYPIUM ARBOREUM *RACE* BENGALENSE

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FOREWORD

India has been famous for her cotton textiles since times immemorial. The most ancient cotton fabrics known to the world, believed to be at least five-thousand years old, were unearthed at *Mohen-jo-daro*, which have been identified as belonging to the present *desi* cotton of northern India. Right up to the eighteenth century, this country retained its supremacy in the production of cotton goods, and the muslins manufactured in Dacca in East Bengal were renowned all over the world as "webs of woven wind." It was only after the Industrial Revolution in England that the Indian textile industry began to decline and the country came to depend on imported machine-made fabrics. At the beginning of the present century, we were importing cotton textiles worth several million rupees. The quality of indigenous raw cotton also suffered in consequence. It was at this juncture that the Indian Central Cotton Committee came into being. It is a matter of great satisfaction that this Committee, in co-operation with the State Departments of Agriculture, has been able to restore in great measure the importance of India as a producer of cotton and cotton fabrics. The country has once again become self-sufficient in respect of its requirements of cotton up to a staple length of 1-1/16 inches. Among the most important schemes now operating for the production of high quality cotton is that designed for the cultivation of Sea Island cotton which is recognised to be the best variety suited to Indian conditions.

Considerable research has already been done on various aspects of cotton culture, such as breeding, agronomy, physiology, pests and diseases, etc. In a country where the soil and climatic conditions vary from one part to another, it is very difficult for research workers to find solution to the numerous problems which face the cultivator. It is a matter of great satisfaction, therefore, that in spite of numerous difficulties, technical as well as financial, our research schemes have progressed satisfactorily and we are moving rapidly towards a position of self-sufficiency and stability. All these achievements

need to be systematically recorded for the benefit of the cotton industry and the large number of research workers engaged on difficult problems. I am glad, the Indian Central Cotton Committee has taken the initiative to bring together all available information on the work which is being carried on in different parts of the country, and to publish it in four handy volumes of a standard monograph. I am sure, these volumes will be read eagerly by all those interested in the industry. I congratulate the Committee on the service they have done to the Country.

S. K. PATIL
Minister for Food and Agriculture
Government of India

New Delhi
February 1960

PREFACE

A comprehensive Monograph on Cotton, embodying the results of researches carried out so far in India and abroad, has been a long-felt need of all those connected with the industry. At the meeting of the Indian Central Cotton Committee held in February, 1956, I suggested that a Monograph on Cotton, in which all research work done so far be incorporated, be brought out. I am glad Dr. B. L. Sethi, Secretary of the Indian Central Cotton Committee, enthusiastically undertook the compilation of such a monograph. A publication of this nature is possible only with the co-operation of a large number of experts in different disciplines, and despite a number of handicaps he has been able to get the material ready for printing all the four volumes of the Monograph.

The role of cotton in the economy of India needs no special emphasis. Cotton cultivation occupies an area of about 20 million acres in the country which is about six per cent. of the total area under all crops. The number of people who depend on the industry for their livelihood, as cultivators, manufacturers of textiles or middlemen, is too large to be assessed accurately.

A good deal of research work has been successfully carried out in India and abroad on this important fibre crop, and a large volume of valuable information lies scattered in scientific journals, bulletins and unpublished records. The intention behind publishing this Monograph is to bring together all this information in a handy form so that it may be readily available to all those who are connected with the cotton industry as research workers, growers or traders.

Systematic work on cotton in India, as on other crops, was started after the establishment of the State Departments of Agriculture at the beginning of the current century. However, full scale planning became possible only after the establishment of the Indian Central Cotton Committee in 1921 as a result of the recommendation of the Indian Cotton Committee appointed by the Government of India in 1917 to study the problems of the cotton crop.

This Commodity Committee is the oldest organisation of its kind in the country, having been constituted even before the inception of the Indian Council of Agricultural Research. It is mainly due to the efforts it has been making during the last thirty-eight years of its existence, that the cotton industry has revived from the slump in which it had fallen after the Industrial Revolution in England. The various volumes of this Monograph record the progress of research on different aspects of the work done so far in India and other important cotton growing countries. A number of scientists and experts have collaborated in the compilation of these volumes. On behalf of the Indian Central Cotton Committee, I thank them for their valuable contribution, and trust that the Monograph will serve as a standard work of reference on cotton.

M. S. RANDHAWA, D.Sc., F.N.I., I.C.S.
President
Indian Central Cotton Committee

New Delhi
February 1960

INTRODUCTION

The Indian Central Cotton Committee at its meeting held on the 3rd February, 1956, accepted the recommendation of its Policy Sub-Committee that a Monograph on Cotton should be published to make available to the various educational and research institutions and the enlightened cotton growers a comprehensive account of cotton in all its aspects on a regionwise basis, and approved the appointment of a small Sub-Committee consisting of Dr. B. N. Uppal, Agricultural Commissioner with the Government of India, Dr. B. P. Pal, Director, Indian Agricultural Research Institute, Dr. B. L. Sethi, Secretary, Indian Central Cotton Committee, Dr. S. M. Sikka, Head of the Division of Botany, Indian Agricultural Research Institute, and Dr. C. Nanjundayya, Director, Technological Laboratory, Matunga, Bombay. It was recommended that the expenditure on this account should be borne by the Committee.

The Monograph Sub-Committee discussed at length the divergent needs that the Monograph would serve. It was decided that the Monograph should deal with the subject on an all-India basis in a technical manner to serve the requirements of the research and educational institutions, and should also give a regionwise account of different subjects in a simpler form. It also considered in detail the set up of the different volumes and chapters of the Monograph, and assigned the writing of the chapters to appropriate experts. Further, the Monograph Sub-Committee recommended that the final editing of the material should be entrusted to Sarvashri Kalidas Sawhney, Retired Agricultural Advisor, Community Development Ministry and Prem Nath, Editor (Books), Indian Council of Agricultural Research.

It was decided that the entire Monograph should be published in four Volumes comprising the following chapters:

Volume I: History of Cotton; Climate and Soils; Taxonomy; Morphology; Embryology; Breeding; Cytology; and Genetics.

Volume II: Physiology; Agronomy; Diseases; Insect Pests; and Seed Multiplication.

Volume III: Technology; Ginning and Pressing; Marketing; Consumption of Cotton (seed); Consumption of Cotton (lint); Legislative Measures; and Exports and Imports.

Volume IV: Northern *hirsutum-arboreum* Region; Central *arboreum* Region; Southern *hirsutum* Region; Central *hirsutum-arboreum-herbaceum* Region; Western *herbaceum* Region; and Eastern Region.

Material for the above volumes has been compiled. While Volume I is being released now, the remaining three volumes are expected to be printed shortly.

The present Volume consists of eight chapters, contributed by Dr. B. L. Sethi, Dr. S. M. Sikka, Prof. R. H. Dastur, Shri P. D. Gadkari, Shri R. Balasubrahmanyan, Prof. P. Maheshwari, Shri N. S. Ranga Swamy and Dr. A. B. Joshi. The Indian Central Cotton Committee is grateful to these scientists for the co-operation they have given in this arduous undertaking.

I must express my profound gratitude to the President of the Indian Central Cotton Committee, Dr. M. S. Randhawa, but for whose sustained interest at all stages of the compilation of the Monograph it would not have been possible to bring out this Publication.

Some of the illustrations and tables in the present Volume have been reproduced with the permission of a number of institutes and scientists. I owe grateful acknowledgements to them — to Meta S. Brown and Margaret Y. Menzel for tables 2 and 3 from their article in the *Journal of Genetics* (Vol. 37, No. 3), figure 1 (Vol. 37, No. 6), and figure 1 (Vol. 39, No. 4) of the same journal; to Margaret Y. Menzel for figures 1 and 6 from the *Journal of Genetics* (Vol. 40, No. 2); to Dr. S. G. Stephens for table 1 from his article in the *Journal of Genetics* (Vol. 39, No. 5); to Dr. R. L. Knight for the appendices 1, 2 and 3 of the *Abstract Bibliography of Cotton Breeding and Genetics*, 1900-1950 (published by the Commonwealth Agricultural Bureau, England); to R. S. Silow and Chi Pao Yu for table 4 from the *Journal of Genetics* (Vol. XLIII, April, 1942), and to Dr. J. B. S. Haldane, Indian Statistical Institute, Calcutta, for granting permission in respect of this article; to Dr. S. C. Harland for the table appearing on page 70 of his book *The Genetics of Cotton* (published by Jonathan Cape Ltd., London); and to the Principal, Agricultural College

and Research Institute, Coimbatore, for loaning a copy of the *Botanical Gazette*, (Vol. 43), for reproduction of some illustrations. I am also indebted to the Council of Scientific and Industrial Research, for allowing the reproduction of the coloured plate of *Gossypium arboreum* race *bengalense* appearing in the article on *Gossypium* Linn of the Wealth of India—Dictionary of Indian Raw Materials and Industrial Products.

I must also record my gratitude to members of the Indian Central Cotton Committee, particularly, the Vice-President, Shri Madanmohan R. Ruia, Shri R. G. Saraiya, Shri Chimanlal B. Parikh and Shri Chunilal B. Mehta, for the valuable suggestions and encouragement received from them. The staff of the Indian Central Cotton Committee, particularly, the members of the Monograph Section also deserve thanks for the zeal and interest with which they have worked to complete this Monograph.

I am also grateful to late Shri Kalidas Sawhney, who edited the first few chapters and to Shri Prem Nath, Chief Editor, Indian Council of Agricultural Research, for finally editing the material and advising on various matters concerning the publication of the Monograph. Thanks are also due to Shri N. S. Bisht, Director of Arts, Indian Council of Agricultural Research, for supplying the design of the jacket and the layout of the illustrations.

B. L. SETHI
Secretary
Indian Central Cotton Committee

Bombay
February 1960

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CHAPTER I

HISTORY OF COTTON

No agricultural commodity in the world has exercised such a profound influence on men and matters as cotton has done from time immemorial. With a history going back to unrecorded antiquity, the fibre has maintained its pristine purity and importance to this day. In India it has had the pride of place among the cash crops from the earliest times. It finds mention in the *Rig-Veda*, the oldest scripture of the Hindus. Manu the Law-giver also refers to it in his *Dharma Shastra*. It was the excellence of Indian cotton fabrics, famed as 'webs of woven wind', which impelled European countries to seek new trade routes with India. It was again the race for supremacy in the manufacture of cotton fabrics which led to the scramble for raw cotton in the 19th century.

To solve the problem of raw cotton supplies for the Indian textile industry as well as for export, the Indian Central Cotton Committee was set up in 1921. India had once again become an exporter of textile fabrics, and there was a pressing need for strenuous effort to produce the best quality cottons. The Committee had to find ways to meet this need. An account of the work done so far and the problems on which research workers in the country are engaged today is given in the various chapters of this monograph.

In respect of acreage, India now occupies the foremost position among the cotton growing countries of the world. In respect of production, however, it has the third place, the first two being taken by the U.S.A. and the U.S.S.R. Table 1 shows the present position of cotton production in different countries of the world.

Cotton is grown in the country from the Sub-Himalayan region in the north to Cape Comorin in the south, its cultivation being confined mainly to areas lying between longitudes 70° and 80°. This enormous cotton tract has been divided into six regions on the basis of species and tracts : (*i*) Northern *hirsutum* region, comprising the Punjab, western Uttar Pradesh, Delhi and North-west Rajasthan ; (*ii*) Central *arboreum* region, comprising Madhya Pradesh, South Rajasthan, South Saurashtra, Vidarbha, Marathwada and Khandesh tracts of Bombay State ; (*iii*) Western *herbaceum* region, comprising Gujerat, Kutch and North Saurashtra of Bombay State and Belgaum, Dharwar and Bijapur districts of Mysore State ; (*iv*) Central *herbaceum-arboreum-hirsutum* region, comprising Andhra Pradesh and Mysore States ; (*v*) Southern *hirsutum-arboreum* region, comprising Madras and Kerala States ; and (*vi*) Eastern region, comprising Assam, Tripura, Bengal, Orissa and Bihar States.

TABLE 1. AREA AND PRODUCTION OF COTTON IN MAJOR COTTON GROWING COUNTRIES (1956-57)

Country	Area (thousand acres)	Production (thousand bales of 478 lbs. each)
Mexico	2,144	1,800
U.S.A.	15,651	13,029
India	19,843	4,050
Iran	519	285
Pakistan	3,560	1,400
Syria	673	428
Turkey	1,532	650
Argentina	1,375	520
Brazil	4,000	1,350
Peru	556	450
Belgian Congo	875	250
Egypt	1,715	1,498
Fr. Equa. Africa	902	165
Mozambique	725	140
Sudan	764	620
Uganda	1,569	315
China	10,500	3,100
U.S.S.R.	5,100	6,000
Others	5,068	1,997
Total	77,071	38,047

Since the discovery of the *Mohen-jo-daro* relics the history of cotton and cotton manufacture has come to be treated as beginning from the times of the ancient Indus Valley Civilisation which flourished in India about five thousand years ago. A close study of these relics in the collection of the Technological Laboratory of the Indian Central Cotton Committee indicates that the early coarse cotton from which the fabrics were manufactured had been produced from a plant closely related to the *arboreum* type.

One of the army Generals of Alexander the Great during his sojourn in India described cotton "as a plant from which the natives plucked the vegetable wool which they spun into admirable clothing." Another Grecian named Nearchus reported that there were in India shrubs bearing tufts or bunches of wool, and from this wool the natives made garments of surpassing whiteness — "a shirt, or tunic, reaching to the middle of the leg, a sheet folded about the shoulders, and a turban rolled around the head." This description tallies closely with the costume worn by the Hindus even to this day. The

following description of the cotton plant is reported to be from Theophrastus' book on Botany :

> "The trees from which the Indians make their clothes have leaves like those of the black mulberry, but the entire plant resembles the dog-rose. They are set out in furrows on the plains, at a distance resembling a vineyard. These wool-bearing shrubs have leaves like the grape-vine, but smaller. They bear no fruit, indeed, but the pod containing the wool resembles a spring apple, while this pod is still unripe and unopened. When ripe, it bursts open. The wool is then gathered from it and woven into cloth of diverse qualities; some inferior, and some of considerable value."

The close resemblance between cotton fibre and lamb's wool seems to have given rise to the legendary 'vegetable lamb'. Heredotus is said to have described cotton as "trees, bearing, as their fruit, fleeces which surpass those of sheep in beauty and excellence." With the passage of time, this description gradually seems to have given rise to the idea that the cotton plant was something bearing fruits "within which there is a lamb, having fleece of surpassing beauty and excellence."

The Greeks named fine muslins *gangitiki* after the source from which they were obtained, viz., the Gangetic area. Subsequently, cotton fabrics became the Roman apparel of luxury. Knowledge about cotton cultivation and manufacture of cotton textiles appears to have been introduced into Spain in the early centuries of the Christian era. There is no doubt that cotton was to India what silk was to China and flax to Egypt. In fact, all available evidence proves that India was the original habitat of cotton. The craftsmen of the Indus Valley Civilisation had achieved a high degree of specialization in the art of weaving, and this would not have been possible without a centuries old tradition of growing and spinning cotton. It may be mentioned in this connection that a *Mohen-jo-daro* fabric tested at the Technological Laboratory of the Indian Central Cotton Committee has been found to have been made from 34's warp and weft, with 60 ends and 20 picks per inch. The spinnability of *arboreum* to 34's is not uncommon even to this day in many parts of India where hand spinning is still practised in the old style.

There is sufficient evidence to show that India was having a flourishing export trade in cotton and cotton goods as early as 569-525 B.C. Two Arabian travellers, describing Indian fabrics, have recorded that the "garments were of such extraordinary perfection that nowhere else were the like to be seen, being woven to that degree of fineness that they might be drawn through a moderate size ring." Marco Polo mentioned the coast of Coromandel as producing "the finest and most beautiful cottons." Likewise, it was reported that "the texture of a muslin was so delicate that when a man puts it on, his skin would appear as plainly through it, as if he were quite naked." It was also said that "with the aid of a bamboo spindle not much larger than a darning needle, and rotated upon a piece of hollow shell to keep from breaking the thread, a single pound of lint could be spun by Indian craftsmen to a length of 253 miles and the delicate woven fabric was of both

plain and ornamental variety, some white and some beautifully coloured." Reverend William Ward, writing at Serampore early in the 19th century mentioned that a muslin manufactured there was so exceedingly fine that when "laid on grass and the dew has fallen upon it, it was no longer discernible."

The cotton goods, in the trade with the West, were carried either on camels or in boats which plied between India and the Middle East. They were so cheap and plentiful that the Roman General Mark Antony gave to his men the comparative comfort of light cotton clothes.

The desire of the European countries for freer intercourse with India, which the Italian Renaissance is believed to have created and the subsequent discovery of a sea route *via* Cape of Good Hope, marked the beginnings of a new era in the history of Indian cotton. A period of new prosperity was ushered in by trade with the western countries in cotton goods. The imports from the various oriental countries stimulated greater exports from the West.

Cotton made its appearance in England first as a luminant in 1298 A.D., when it was used for the preparation of candle-wicks. The British East India Company received a royal charter in 1600, and shortly thereafter imports of cotton fabrics in England became common. The first consignment of Indian fabrics reached that country in 1631. The inflow of Indian fabrics expanded rapidly to the detriment of the British wool interests. A good deal of agitation ensued which led to the enactment of a law in 1666 stipulating that every dead person in England be buried in a woollen shroud or in default of it a penalty of five pounds be realised by the undertakers. In 1696, a pamphlet entitled 'The Naked Truth' declared that muslins were "becoming the general wear in England." In 1708, an Act was passed by the English Parliament prohibiting the import of Indian silks and printed calicos for domestic use either as apparel or furniture, under a penalty of 200 pounds. This, however, did not afford much relief as is evident from the following observation of Daniel Defoe :

> "General fansie of the people runs upon the East Indian goods to that degree that the chints and printed calicos, which before were only made use of for carpets, quilts, etc., and to clothe children and ordinary people, became the dress of our ladies..... Nor was that all, but it crept into our houses, closets, and bed chambers; curtains, cushions, chairs and at last beds themselves, were nothing but calicos or Indian stuffs; in short, almost everything that used to be made of wool or silk, relating either to the dress of the women or the furniture of our houses, was supplied by the Indian trade. The several goods bought from India were made five parts in six under our price, and, being imported and sold at an extravagant advantage, were yet capable of under-selling the cheapest thing we can set about."

The Industrial Revolution in England brought about stupendous economic changes following the invention and large scale use of cotton manufacturing machinery. Watt's Steam Engine, Hargreaves' Spinning Jenny, Arkwright's Mule, Cartwright's Loom, and Kay's Fly-shuttle soon outmoded

the artisan's craft and also led to a complete change of policy towards cotton goods. In his book 'Cotton as a World Power' James A. B. Scherer observes :

> "Convinced finally that the seductive Indian goods had permanently enchanted the fancy of her people inspite of political eloquence and excise laws and penalties, she taught her weavers surreptitiously to imitate the forbidden fripperies, and then at length the spirit of indomitable enterprise awakened, so that England resolved to take this fleecy stuff from the Orient, and, by sheer application of brain power, turn disaster into opulence through a manipulation more dexterous than that of the Hindus themselves."

The rapid development of the cotton industry brought unprecedented prosperity to England. On the other hand, the affairs of the Indian cotton textile industry took a turn in the reverse direction.

The British East India Company, who were governing India before the Industrial Revolution, had adopted a policy which permitted "the utmost latitude to weavers of cotton and silk with a view to encouraging manufactures." About a hundred years later, the Directors of the Company issued instructions to their representatives in Bengal "to encourage the manufacture of raw silk and discourage the manufacture of silk fabrics." These instructions applied to cotton manufactures as well. The invention of cotton machinery increased Britain's requirements of raw cotton enormously and the imports of raw cotton into Britain rose from less than four million lb. in 1764 to about 56 million lb. in 1801. India was then the principal source of cotton supplies, and the East India Company made special efforts for the production of better and cleaner cotton in the country for use in England. In his letter, dated May 31, 1842, to the Court of Directors, Lord Ellenborough, the then Governor General, stressed that the object of this policy was not merely to improve the Indian cotton but also to grow improved varieties so extensively and so cheaply as to undersell and supplant the Americans in the English market and thus make England independent of foreign supplies in respect of the raw material needed for her principal industry.

With the change over from the export of textiles to that of raw cotton, attention in India came to be directed more and more towards the production of raw cotton. The production stabilised itself by 1900 and thereafter showed a gradual increase with few fluctuations up to 1941-42, the early years of the Second World War. It received a serious setback after the partition of the country. Vigorous attempts have since been made to make good the loss, and the country is now in a happy position to be able to meet the requirements of its textile industry, except for a small quantity of some six lakh bales of extra-long staple types which are still being imported from foreign countries.

Cotton cultivation in India is beset with a number of handicaps, the most important one being the unevenness of rainfall. As the crop in a large part of the country depends on the commencement of the monsoon and the distribution of the precipitation during the season, the production varies from

tract to tract and season to season. Added to this is the great variation found in the soils of India. The soil-climatic complex has such a profound influence on the growing of cotton that there are fine distinctions within even a particular tract to contend with, when the question of the improvement of cotton is taken up.

Furthermore, the need for growing long staple cotton of the *hirsutum* variety which dates back to the middle of the last century has brought in its wake not only the problems of growing but also of controlling a number of pests to which the crop is susceptible. The problem is further complicated by the presence of more than one species of cotton being cultivated commercially in the country. Actually, there are two main Asiatic species, *arboreum* and *herbaceum*, in addition to *hirsutum*.

INTRODUCTION OF AMERICAN COTTON

The fortunes of Indian cotton seem to have been always linked with the adequacy or otherwise of cotton exports to England from America. Extensive trials with exotic cottons had been conducted by the East India Company in different parts of the country over a long period of time in an attempt to develop an alternative source of supply. These trials mark the beginnings of the work on the improvement of cotton in India. A brief account of the various attempts at introducing American cotton in the different Provinces is given below.

Bombay. The history of the introduction of American cotton into India dates back to the second half of the 18th century. In Bombay, the first attempt was made in 1790 when seed of Bourbon cotton was obtained from Malta and Mauritius and distributed. Strains of this cotton are still found in certain parts of the cotton tracts of the Deccan as well as in Konkan. A fresh supply of seed was obtained from Mauritius in 1812 and distributed to the Collectors of Surat and Broach, but the trials proved a failure. The experiments continued thereafter in Kaira, by Dr. Gilders, also failed. Of the 12 American cotton planters who were brought to India in 1840, three were allotted to Bombay where they started work at Broach. Trials with exotic American cotton were carried out in Gujerat, the Deccan and Konkan. It was only in Dharwar area that some results were obtained. New Orleans seed was grown there in 1842 in Hubli *taluka,* and the area under it registered a peak acreage of 1,78,682 by 1861-62. It is on record that Dharwar-American cotton was cheaper by 1-1·5/8 d. per lb. compared to Kumpta, in 1850-51. This difference, however, seems to have dropped to a farthing in 1859. Steps were taken to prevent careless sowing of mixed American and *desi* cottons and also to ensure that saw gins used for ginning American cotton were properly utilised. These steps seem to have brought about a great improvement in the quality of cotton.

Further trials were undertaken by the Cotton Superintendents and the Cotton Commissioner appointed in the Province, and fresh attempts were made to introduce Dharwar-American, Hinganghat and Broach into parts of the Presidency in which they were not grown before. It is reported that in 1897-98 Mollison, the then Deputy Director of Agriculture, came to the conclusion that exotic varieties of cotton were unsuited to conditions of Indian agriculture, that an indigenous variety found suitable in one district might prove unsuitable in another, and that the only hope of improvement lay in taking up for propagation, the varieties that were found in general cultivation and improving them progressively by proper selection of seeds from year to year. It appears that from this time onwards attempts to introduce exotic cottons into Bombay Presidency practically ceased, though experiments with American and Egyptian varieties continued to be conducted on farms during the period from 1905 to 1910. The work on American cotton which was done for some years at Dharwar, was transferred to Gadag in 1912. As a result of tests on Upland Georgian and New Orleans types, it was found that the former was more immune to the effects of climate and insect pests than the latter. Further attempts were directed towards eliminating the undesirables from the mixture.

Madras. The efforts in Madras commenced in 1790, when the Bourbon cotton seeds obtained from Malta and Mauritius were first distributed among the cultivators. The surviving relic of this introduction is the Bourbon cotton which has become naturalised and is found only in the districts of Salem and Coimbatore. The next step was to allot three of the American planters to Madras who commenced work in the Tinnevelly district where the *ryots* refused either to adopt the American method of cultivation or to sow the American seed unless Government guaranteed purchase of the produce. Trials with New Orleans, Sea Island and Bourbon cottons were thereafter undertaken on the four farms established in Coimbatore district, but the results proved unsatisfactory. For some years after the reorganisation of the Madras Agriculture Department in 1905, American, Peruvian, Egyptian, Sea Island and Caravonica cottons were experimented with on the farms at Bellary, Attur, Taliparamba and Hagari, but without success. Subsequently Cambodia cotton, an exotic American variety, acclimatised originally in Cambodia (Indo-China), was introduced in Madras State in the year 1907. Its performance under irrigated conditions was encouraging, and subsequently it became popular with the cultivators.

Punjab. The first attempts at growing American cottons in the Punjab were made in 1853 when some seed was distributed by the Deputy Commissioner of Shahpur. Subsequently, in 1876-77, the seed obtained from Dharwar was distributed in parts of the Province. Serious attempts at introducing American cotton in the Province, however, commenced from

1902, when a variety known as Punjab Narma was found growing in Shahpur, Jullundur and Lahore districts. Till 1911, with the exception of Jhang district where cultivators kept their own seed, the success achieved was insignificant. The practice of importing seed from Dharwar was abandoned in 1912 as it became evident that American cotton grown in the Punjab was superior to that of Dharwar. Selection work was started at Lyallpur by Dobbs, the then Principal of the Agricultural College, and was continued by Milne, the Economic Botanist, which resulted in the evolution of cotton varieties 3F and 4F in 1912. 3F, which was a smooth-leaved type, proved a failure being susceptible to jassid attack. 4F, a rough-leaved Upland type and a selection from Punjab Narma appeared to have proved immune to jassid attack. The total area under American cotton in the Punjab in 1913 was some 30,000 acres. Since then, 4F variety spread rapidly, and in 1917 out of the total area of 2,76,000 acres under American cotton in the Province about 1,80,000 acres were covered by it.

Uttar Pradesh. Experiments on growing long staple cotton in Uttar Pradesh commenced in 1826. Four of the 12 American planters brought to India were stationed in the Province, but their efforts ended in complete failure. Though the experiments on the exotics at Allahabad were dropped, those at Kanpur continued and an acclimatised variety of mixed origin, known as Cawnpore-American, was eventually evolved. Up till 1909, the Agriculture Department used to purchase the *kapas* of ordinary local cotton, from the cultivators at a premium of two rupees per maund, gin it and dispose it of to the mills, distributing the profit among the cultivators as bonus after meeting the expenses. Under this arrangement, the area under American cotton increased considerably. In 1909, however, the Central Government objected to this arrangement, because large amounts were required as advances to finance the purchase of the crop. This brought about a complete cessation of the cultivation of American cotton within a few years. Fresh attempts to revive American cotton cultivation commenced in 1912 in the neighbourhood of Kanpur. Subsequently, the work in connection with the improvement of Cawnpore-American cotton in Uttar Pradesh was mainly done by Burt, the then Deputy Director of Agriculture.

Central Provinces and Berar. Experiments with the exotic cottons in this area more especially with Egyptian and Brazilian varieties, date from about 1839. The early experiments proved infructuous. The only significant fact worthy of mention is the introduction of Upland Georgian which still survives in the mixture of varieties grown in the tract. After the reorganisation of the Provincial Agricultural Department, research was again taken up. The seed of the acclimatised American Upland Georgian was released from Nagpur Farm for the first time in 1903-04. The work continued for three or four years after which it was abandoned. This variety

of cotton is now known as Buri. Though the reports of Buri cotton were favourable, it was only Roseum that was encouraged in the Province. Buri has since been acclimatised in Burhanpur *tehsil* of Nimar district.

DEVELOPMENT WORK BY AGRICULTURAL DEPARTMENTS

The different problems concerning the cultivation of cotton as of other crops in India came to be studied on scientific lines only with the establishment of the Agricultural Departments in the various Provinces and princely States in 1904. The Departments usually consisted of two sections, the Research and the Propaganda. While the staff of the former were engaged in the study of the crops already grown, cultivators' methods of producing them, varieties available and their suitability for the tract, marketing practices, etc., the personnel of the latter concentrated on propaganda amongst the cultivators for growing pure crops and adopting improved methods of agriculture. Cotton was one of the principal crops handled by the Departments, particularly in areas where the acreage under the crop was high. Systematic study of cotton cultivation revealed that the so-called varieties grown in India consisted of a mixture of types varying greatly in morphological and economic characters, such as, leaf shape, stem pigment, presence of nectaries, hairiness, duration of the crop, bud, flower and boll formation, staple length, ginning outturn, fibre strength, boll size, spinning capacity, etc. The Departments of Agriculture in Bombay, Madhya Pradesh (Central Provinces and Berar), Uttar Pradesh, the Punjab and Madras started cotton research work on an elaborate scale and thus were pioneers in respect of selection of improved strains from the existing mixtures. Improvement was effected chiefly in regard to lint quality and increase in yield.

Gammie in Bombay had made a very successful survey of Indian cottons and published the results of his study in the Pusa Memoir, Botanical Series Vol. II, No. 2, 1907, which contains comprehensive notes and beautiful pictures of the various types then grown in the Provinces. Hilson and Ramanatha Iyer were the earliest workers in Madras. Co.1 from Cambodia, N.14 from Northerns, H.25 and H.1 from Westerns and several other strains stand to the credit of Hilson whose foresight has stood the test of time. It may be stated that N. 14 which he had isolated stands to this day supreme in the field having not been replaced by any strain superior to it in quality. Co. 2 which was a more robust and cosmopolitan strain than Co.1, was isolated by Ramanatha Iyer. Milne in the Punjab, as already mentioned was responsible for the isolation of 4F cotton from the acclimatised Punjab-Americans. Subsequently, it was Labh Singh who isolated an early maturing selection known as L.S.S. Youngmen and Mahta were responsible for the selection of V. 262 and V. 434, respectively, in Central Provinces. In Uttar Pradesh, the work of cotton improvement was undertaken by Leake and Ram Prasad who were responsible for the isolation of C. 520. Subsequently, Bryce Burt

working on American cotton in Uttar Pradesh isolated a strain known as C.A. 9. Fletcher was responsible for the isolation of the famous 1027 A L.F. from a cross between Kumpta and Goghari suitable for cultivation in Surti tract. Kottur was responsible for the evolution of Jayawant for Kumpta tract, M.L. Patel for B.D. 8 and Wagad 8 and Prayag for Banilla and Jarila.

These improved strains in the several Provinces made good headway because of intensive propaganda based on their intrinsic merits and the organisation set up for the large scale multiplication and distribution of the improved seed for general cultivation. All the same, large tracts of the cotton growing regions were still cultivated with the unimproved bulks, and owing to paucity of funds and personnel the progress in the introduction of improved varieties was slow. Another significant reason was that cotton was one of the several commodities that had to be taken care of by the Agricultural Departments. The idea of having Crop Specialists had not taken shape. The work that had to be tackled by the Departments was colossal in view of the fact that vast stretches of land had to be attended to. Added to these difficulties were the natural conservatism of the Indian cultivator and the outmoded agricultural practices which held the field. The bulk of the cotton grown in the country, therefore, continued to be of mixed short staple Asiatic types.

Despite all these handicaps, the Departments of Agriculture had initiated a good deal of scientific work. Posts of Crop Specialists had been created at the Agricultural Research Institute, Pusa, and also in Madras and Bombay Provinces. The other Provinces had different organisations with posts of Deputy Directors or Economic Botanists, etc., to deal with several crops. The Government of India had also created the post of Imperial Cotton Specialist with his Headquarters at Kirkee. This development paved the way for further intensive work to be undertaken.

Position in 1913-14. From the Report on the Progress of Agriculture in India for 1913-14, it can be seen that in Madras considerable improvement had been effected in raising the general level of the crop, particularly in Tinnevelly tract, by distribution, through a chain of seed farms, of better quality seed obtained by bulk selection, and introduction of the seed drill and bullock hoe for sowing and interculture, respectively. The crop in this tract consisted of a mixture of two varieties, and the seed was sown broadcast which admitted of no cultivation after sowing. The advantages of seed selection from one variety combined with improved cultivation were so obvious by 1910-11 that an area of nearly one lakh acres in the district came to be under one variety. Subsequently, owing to the establishment of ginning factories which ousted the old hand gins, it became difficult for the cultivators to get back pure seed. The policy of seed distribution had, therefore, to be revised. The area of seed farms had been restricted to about 500 acres

which could be sown with seed raised on the Government Farm at Koilpatti. The seed from these farms was then sold to villagers, and arrangements were made with ginning factories for the processing of any consignment of cotton which they might take to them. A large demand was thus created for selected seeds at prices 40 per cent. above the rate for ordinary *bazar* seed.

Side by side, with the bulk selection, the Madras Agriculture Department carried out single plant selections on the Government Farm, with the result that it succeeded in isolating three single strains of marked superiority in quality and ginning percentage over the ordinary selected variety. The increased profit from these strains over the bulk selection was estimated at Rs. 12 to Rs. 16 per acre.

Cambodia cotton was by then thoroughly established in the south of Madras Presidency, and was a striking example of an extremely valuable introduction by the Agriculture Department. Owing principally to its capability of being grown profitably on lands unsuited to Indian cotton, its cultivation spread rapidly from the very beginning. It had supplanted crops which, on an average, gave a profit of Rs. 30 per acre. In 1912, there were about 60,000 acres under it, yielding a profit of Rs. 180 per acre. It was claimed that in that year alone, this variety added Rs. 90 lakhs to the income of the agricultural community. Owing to its lucrative nature, it dominated the attention of both the growers and the dealers to such an extent that it began to be grown on unsuitable lands. The carelessness with which it was handled, coupled with the adulteration with unimproved local varieties which the middlemen practised resulted in further deterioration of its quality. The efforts of the Agriculture Department were then directed towards the selection and breeding of this cotton on a large scale and advising the cultivators to restrict its cultivation to suitable areas only.

Cambodia cotton had also been introduced in some parts of Mysore where it became one of the most important crops.

In Bombay it had been realised from past experience that an improved cotton must have the following characteristics, in order that it might obtain rapid success : (*i*) improvement must be in quantity rather than in quality ; (*ii*) improvement in quantity must be considerable and obvious ; and (*iii*) cultivation must involve no additional labour and risk to the cultivator. Viewed from these points, the efforts made by the Agriculture Department in Khandesh in spreading the cultivation of Roseum cotton possessing heavier yield and higher ginning percentage than local mixture, were most successful. It fetched six rupees more per acre than the local types did. Cambodia cotton was spreading in the south of Dharwar district and it appeared probable that it might find a permanent place in the crops of the locality.

The main feature of the cotton work in Central Provinces had been the distribution of Roseum seed through proper cotton seed farms organised on a co-operative basis in Berar.

In Uttar Pradesh, the factors controlling ginning percentage of Indian cottons were being studied. In the western districts of the Province, the cultivation of white-flowered cotton giving a higher ginning outturn and better yields than the existing mixture was rapidly extending. In the central districts, Cawnpore-American cotton was found to be promising and seed for about 5,000 acres had been issued by the Department.

In the Punjab, the cultivation of American cotton received a setback owing to a large scale attack by jassids in 1913, when the Government sanctioned the payment of compensation to those, whose crop was very poor. About 400 maunds of seed of hardy immune type were issued or sold by the Agriculture Department and were sown mostly under seed farm conditions. It was reported that there were certain difficulties in the way of effecting a permanent improvement, and that these had to be surmounted before substantial results could be achieved. The difficulties encountered by the Agricultural Department were in respect of : (*i*) organisation of seed distribution for supply of pure seed ; (*ii*) prevention of adulteration in both the seed and the lint ; and (*iii*) infusion of confidence among the buyers and the spinners. It was concluded that the whole work might be conceived as that of primary concentration of effort on a few places which should be followed by ultimate radiation of the results over a larger area.

Position in 1919-20. The Report on Agricultural Operations in India for 1919-20, shows that it had come to be realised that the cotton crop was of vital importance to the entire country, excepting North-east India, and that along with wheat and rice, it was engaging the attention of all the Agricultural Departments. Bombay headed the list of the cotton growing Provinces, followed by Central Provinces, Hyderabad, Madras, the Punjab, United Provinces and Central India.

In Bombay Presidency, a large number of exotics, both selections and crosses, had been tested in different tracts. In Gujerat, an area of 6,000 acres was sown with Selection 1A and the produce was auctioned under departmental arrangements at a premium of Rs. 22 to Rs. 75 per candy above the market price of Surat cotton. The profits accruing from the cultivation of N.R. cotton, compared with ordinary Khandesh Mixture, were considerable and the Agriculture Department was able to turn over the bulk of the distribution work to the co-operative societies and seed unions. It was also realised that N.R. cotton was admittedly a short staple cotton and efforts had, therefore, to be made for evolving a high yielding cotton with better staple. A strain of Comilla x Bani cross, was tested on a field scale. Dharwar 1 which had been released was not popular with the growers, inspite of a premium over ordinary Kumpta cotton amounting to Rs. 20 per *nag*, owing to its susceptibility to wilt disease. On the other hand, Gadag 1, isolated at the Dharwar Farm, found favour in Dharwar-American tract and was

rapidly taken up. It fetched a premium of Rs. 65 per acre, and in 1919-20 some 10,000 acres were sown with the pure strain.

In Central Provinces, K. 22 cotton had gained popularity in the northern districts, as it gave a high ginning percentage equal to that of Roseum, and was much earlier than the latter variety, which was unsuited to the tract. There was, however, good demand for Roseum seed in the western parts.

In the Punjab, the American cotton crop, composed mainly of type 4F in the canal colonies, had an area of 5·25 lakh acres under it. But it suffered heavily from drought in August-September, 1919, when seed for some 1,000 acres had been distributed.

A survey of the cottons of United Provinces had been initiated with a view to making selection of promising varieties.

In Madras, the progress was well maintained. Cambodia cotton had established itself firmly in South India. Two types, H.25 and N.14, selections from Western and Northerns, respectively, were undergoing tests at Hagari and Nandyal. Cambodia 11 gave the highest yield, viz., 2,168 lb. of *kapas* per acre, representing a profit of Rs. 469, the cost of production being Rs. 76 per acre. To minimise the damage caused by stem weevil and pink bollworm, the Agricultural Pests and Diseases Act was enforced in certain parts of Madras Presidency, whereby the old crops of Cambodia cotton were uprooted by the end of August, 1919. The crop in the following year justified the operation as there was remarkable freedom from damage from bollworm.

Cotton being an all-India crop with wide variations in varieties grown and the methods of cultivation, the need for a co-ordinating body was keenly felt. Added to this, was the urge of the Lancashire mills to be free from dependence on the American produce. All this necessitated the institution of an enquiry into the cotton growing industry. The history of later developments is linked with the establishment of the Indian Central Cotton Committee and the growth of its activities. These are briefly dealt with below.

Appointment of Indian Cotton Committee. In view of lack of proper organisation of the cotton trade, of co-operation between it and the Agriculture Departments, the Governor-General in Council appointed the Indian Cotton Committee under the Resolution of the Revenue and Agriculture Department, No. 933-263, dated September 27, 1917, the first two paragraphs of which are reproduced below :

"The question of extending the cultivation of long stapled cotton in India is one which has frequently engaged the attention of the Government of India. It has again been brought into special prominence as the result of recent investigations by the Board of Trade which have shown the importance in Imperial interests of increasing the production of this class of cotton within the Empire. The Government of India consider it desirable that India should co-operate in the solution of this problem and they believe that the interests of this country in the matter will be found to coincide with those of Lancashire. It has repeatedly been urged by manufacturers in India that it is of even greater importance to them than to manufacturers elsewhere that sufficient cotton of long staple

should be forthcoming in this country and that the extension of the growth of improved cotton would react most favourably on the manufacturing industry. There are certain areas in which there is reason to believe that long staple cotton will give a sufficiently large yield to enable it to be grown at a profit. Here the problem is one mainly of organization. In other areas, which include the majority of the cotton growing tracts in India, a type of cotton combining yield and quality in sufficient degree to enable it to compete successfully with the prevailing short staple types does not appear to have been as yet evolved and the question of research will enter largely into the solution of the problem. An extension of the growth of long staple cotton in the above two cases would, in all probability prove of great benefit to the cultivators owing to the higher prices which long staple cotton commands, provided that the full benefit of these prices can be secured to them by improvements in the system of marketing and by the prevention of the harmful practices of adulteration and damping which have done so much in the past to lower the reputation of Indian cotton. In these circumstances, the Government of India have decided that the possibilities of extending the growth of long stapled cottons in India should be investigated by a Committee constituted as follows :

J. MacKenna, Esq., C.I.E., I.C.S., Agricultural Adviser to the Government of India	*President*
F. Hodgkinson, Esq., Member of the Council of the British Cotton Growing Association	*Members*
N. N. Wadia, Esq., Member of the Committee and Ex-Chairman, Bombay Millowners' Association	
G. S. Henderson, Esq., Officiating Imperial Agriculturist	
W. Roberts, Esq., Principal and Professor of Agriculture, Lyallpur Agricultural College	
H. F. Ashton, Esq., Executive Engineer, Punjab	
F. Noyce, Esq., I.C.S.	*Secretary*

2. The Committee will examine the work which has been done in the various Provinces of India in the establishment of long stapled cottons. It will report regarding the possibility of the extension of any methods which have led to success. It will investigate the causes of failure where this has occurred, and, if it finds that the failure has been due to agricultural, irrigational or economic causes or to administrative difficulties, will propose appropriate remedies. It will carry out a detailed study of local conditions in each cotton growing tract and will enquire into the possibility of improving existing methods of ginning and marketing and also of preventing adulteration and damping. It will further report on the possibility of improving the accuracy of the cotton forecasts and generally of making the statistical information published by the Government of greater utility to the cotton trade. Finally, it will submit recommendations in regard to the staff required and the organization necessary for the development of the cultivation of long stapled cottons in tracts which it considers suitable for that purpose."

In accordance with the above Resolution, the Indian Cotton Committee came into existence on October 8, 1917. The Committee toured the main cotton growing areas, viz., the Punjab, Sind, United Provinces, Central Provinces, Central India (Bhopal, Gwalior and Indore), Bombay, Baroda, Hyderabad and Madras. Evidence of witnesses from Burma, North-West Frontier Province, Bengal, Bihar and Orissa was taken at Poona, Lahore and Calcutta. The Committee held 67 sittings and examined representatives of eight Chambers of Commerce and other bodies connected with the cotton trade and 263 individual witnesses, almost all of whom had previously sent in written memoranda. Of the individual witnesses, 114 were officials from the Agriculture and Public Works (Irrigation) Departments, and 149 non-officials.

One hundred and fifteen witnesses were Europeans, 147 Indians and one Japanese. The Committee had also received written memoranda from 32 individuals interested in the enquiry, who were not orally examined. In addition to visiting almost all the Government Farms in the Provinces, it inspected a large number of ginning and pressing factories and spinning and weaving mills besides holding informal meetings with the cultivators, ginners, brokers, representatives of co-operative societies and other persons connected with cotton. In outlining the conditions which brought about the appointment of the Indian Cotton Committee, it was stated that the cotton interests in England had emphasised that there was a distinct tendency for the world demand for the raw material to outrun the supply, and that consumption had in fact only been limited by the quantity of cotton available. It was mentioned that the total world production in the pre-war (First World War) period was estimated by Prof. Todd at about 25½ million bales, of which the United States produced 15 million bales, that is, nearly three-fifth of the total outturn of cotton. During the first three years of the First World War, the United States' production averaged only 13½ million bales. It dwindled to 12 million bales in 1917-18 and was estimated at 12½ million bales in 1918-19. It was also stated that the consumption by American mills had been on the increase and that the average of the three years 1915-18 was of the order of 7·6 million bales. It was thus felt that unless a fresh source of supply was rapidly developed, the high prices of cotton then prevalent were not likely to fall to any appreciable extent even under normal conditions. The Committee observed as follows :

> "In these circumstances, it is obvious that the Lancashire cotton industry, the importance of which to the Empire needs no comment from us, is faced with a serious situation and that it is most desirable that it should cease to be almost entirely dependent on a source of supply, the future of which is so problematical. It is equally desirable, in the interest of the Empire as a whole, that an alternative source of supply should be found within the Empire. India, as the largest cotton producing country in the Empire and the second largest in the world, clearly offers the greatest possibilities of any considerable increase in the supply of cotton in the near future."

It will thus be noted that the same principle which had led the British East India Company to introduce the American cotton into India, once again provided the impetus for the constitution of the Indian Cotton Committee.

The average annual production in India was about four to five million bales, of which very little quantity was used by the Lancashire mills. The exports to the United Kingdom for five years ending 1917-18 were only 2,15,000 bales. As far as Lancashire was concerned, it was stated that the immediate need was an extension of the cultivation of long staple cotton in India. It was further added that this problem had engaged the attention of the Government of India since 1788. But whereas the efforts to extend the cultivation of cotton, particularly of exotic varieties, during the early part of the last century, aimed at rendering Lancashire independent of the American supply, the

position now was that India herself had a flourishing cotton industry, which was as much interested as Lancashire in obtaining larger supplies of better cotton. While examining the possibility of Indian cotton replacing the American for meeting the needs of Lancashire, the Committee observed that "the only parts of India from which assistance of real value to Lancashire could be expected were tracts in which cotton of an inch or slightly more in staple could be grown in larger quantities." The tracts which answered to this description, were stated to be parts of Madras, growing Cambodia and Karunganni cottons, and the Punjab, where American cotton was making rapid headway. Sind was also considered a potential area for growing Egyptian and American cottons if perennial irrigation was provided by the construction of the Sukkur Barrage.

The enquiries of the Committee, though primarily directed towards determining the possibilities of extending the cultivation of long staple cotton in India, covered a wide field as the problem of securing to the cultivator a proper price for his cotton was closely connected with the prevention of the malpractices of damping, mixing and adulteration, which in turn affected both long and short staple cottons. The Committee, therefore, examined the cotton question in India as a whole and framed its recommendations accordingly.

The Report of the Indian Cotton Committee is divided into two parts, the first dealing with the agricultural and irrigational, and the second with the commercial aspect of cotton production in the country. It consists of 20 chapters, one of which is devoted to the Committee's recommendation for the formation of a Central Cotton Committee. It is stated that in order to secure co-ordination and co-operation in all matters relating to cotton, a Central Cotton Committee of a permanent character composed of representatives of the Agricultural and Co-operative Departments, the Director of Commercial Intelligence, the Director of Statistics and representatives of the trade should be established in Bombay. It was also recommended that the Agricultural Adviser to the Government of India should be the President of the Committee, the staff of which should include a whole-time Secretary and a Technologist.

The Report of the Indian Cotton Committee is a model of clear thinking, not only as regards scientific facts and the cotton situation in each Province, but also regarding the assessment of the needs of the Indian cotton growing industry as a whole. It is indeed a document of very great significance, marking the beginning of a new phase for the improvement of Indian cotton through the establishment of the Indian Central Cotton Committee. The main functions of the Committee as recommended were:

1. To act as an advisory body to the Government and the trade in all matters connected with cotton, including questions relating to legislation and the licensing of the ginning and pressing factories.

2. To act as a centre for the dissemination of information regarding cotton and to assist the Agricultural Department, through its Technologist, in obtaining authoritative valuations of new varieties.

In order to carry out its functions, the Committee was to act through the Provincial Committees and Local Sub-Committees which were recommended to be formed in all the Provinces, except Bihar, Orissa and Assam, in which cotton was grown. In view of the special circumstances of Burma, the Committees there were to serve as advisory bodies in regard to the licensing of the ginning and pressing factories.

The post of the Imperial Cotton Specialist lost its importance with the formation of the Central Cotton Committee. The samples of cotton submitted by the Agriculture Departments for trade valuation were required, in the first instance, to be not less than 20 lb. of lint. If the reports on these were satisfactory, 200 lb. of the cotton grown on a field scale and handled under ordinary conditions was to be sent for a mill test.

The Committee also recommended that one Central Association to be known as the East India Cotton Association should take the place of the seven distinct bodies which at that time controlled the cotton trade in Bombay. This Association was required to: (*i*) establish proper basis of classes of cotton for future contracts; (*ii*) license brokers and commission houses; and (*iii*) establish a clearing house for settlement at least weekly.

All speculative transactions in *kutcha khandis*, *kutcha Americans* or *single and double options* were entirely prohibited.

On its formation, the East India Cotton Association was to devise better methods of classification than those adopted at that time.

ESTABLISHMENT OF INDIAN CENTRAL COTTON COMMITTEE

In keeping with the recommendations of the Indian Cotton Committee, the Indian Central Cotton Committee was established in 1921, as an advisory body, having the following principal functions:

1. It should advise both the Government of India and the Local Governments in regard to any particular questions of cotton policy referred to it.
2. It should recommend both to the Government and the trade such measures as appeared to it suitable for safeguarding the areas of long staple cotton in the various Provinces where these appeared to be endangered as well as for promoting and extending the cultivation of long staple cotton in new areas, such as, Sind and parts of the Punjab.
3. It should bring to the notice of the Government and the trade any changes in the conditions of the cotton growing tracts which may occur from time to time and suggest suitable measures to meet them.
4. It should be consulted by the Government in regard to legislation proposed on any matters connected with cotton. It would also be consulted in respect of any rules framed under any legislation in regard to such matters both by the Government of India or the Local Governments.
5. In conjunction with the East India Cotton Association, it should deal with the question of the trade classification of the different varieties of cotton.

6. It should assist the Agricultural Departments of the various Provinces to obtain authoritative valuations of new varieties of cotton and to get accurate spinning tests carried out.
7. It should keep in close touch with the Provincial and Local Cotton Committees and render them assistance, if required, in regard to the marketing of small quantities of new varieties.
8. It should make recommendations in regard to possible improvements in the forecasts and statistics relating to cotton. The statistical work in connection with cotton, such as the compilation and issue of forecasts of the ginning and pressing returns, and of figures relating to the movement of cotton, especially of shipment and local mill consumption, might eventually be handed over entirely to it.
9. It should act as a bureau for the dissemination of information both in regard to the cottons of India and of other countries to the Agricultural Departments and the trade generally in India and throughout the Empire.
10. Finally, it should publish an annual review of the general cotton position with special reference to the Indian cotton crop.

The Committee became an administrative body under the Indian Cotton Cess Act, 1923, having at its disposal funds which, with the previous approval of the Central Government, could be applied to measures designed for promoting agricultural and technological research in the interests of the cotton industry in India. The Cotton Cess Act of 1923, was amended in 1948 enlarging the functions of the Committee so as to include in its purview the improvement and development of the methods of growing, manufacturing and marketing of Indian cotton. The Amendment Act of 1948 also provided for the representation on the Committee of some of the newly integrated States in which cotton was an important crop. The constituencies now composing the Cotton Committee are shown in Appendix I.

The Vice-Chairman of the Indian Council of Agricultural Research is the *ex-officio* President of the Committee. The Committee usually meets twice a year but its detailed work is carried out with the help of the following Sub-Committees:

1. Standing Finance Sub-Committee.
2. Local Sub-Committee.
3. Agricultural Research Sub-Committee.
4. Technological Research Sub-Committee.
5. Cotton Forecast Sub-Committee.
6. Cotton Ginning and Pressing Factories Sub-Committee.

These Sub-Committees are appointed annually, and they hold office for a period of one year, i.e., from the 1st April to the 31st March.

Set up of the Committee. A full-time Secretary is the Chief Executive Officer, and he is assisted by a Deputy Secretary, an Assistant Secretary, a Statistician, a Technical Officer, a Publicity Officer and two Superintendents, in the discharge of the Committee's day-to-day work.

The Committee has, on its general body, representatives of cotton growers, agricultural officers, cotton trade, textile industry, co-operative banks and cotton ginning and pressing industries. It serves as a valuable forum for discussions on many problems affecting both the cotton production and the

cotton trade in the country. The Committee's primary concern is the interest and welfare of the cotton grower.

The functions of the Sub-Committees already mentioned are as follows:

Standing Finance Sub-Committee: This is the principal executive body of the Committee, and consists of nine members, including the President and the Vice-President who are the *ex-officio* members. The Vice-President is the *ex-officio* Chairman of this Sub-Committee. It exercises all powers of the Committee in regard to the control and the disposal of the funds of the Committee, and deals with the day-to-day administration and all matters involving finance.

Local Sub-Committee: It is composed of local members and those residing near Bombay. There is no limit regarding the total number of the members of this Sub-Committee. It deals with matters of a general nature, not involving finance, which cannot be postponed for consideration at the usual half-yearly meetings of the main Committee.

Agricultural Research Sub-Committee: It is an advisory body to the main Committee on matters relating to research and extension of successful results achieved. It reviews the progress made under the various research, seed distribution and marketing schemes of the Committee, and examines proposals for new schemes or extension of those already in operation.

Technological Research Sub-Committee: This is an advisory body to the main Committee on matters relating to the technological research.

Cotton Forecast Sub-Committee: It deals with questions relating to cotton forecasts and cotton statistics.

Cotton Ginning and Pressing Factories Sub-Committee: It attends to matters arising out of the Cotton Ginning and Pressing Factories Act, 1925.

Funds of the Committee. The Indian Cotton Cess Act of 1923 provided the compulsory levy of a cess of two annas (four annas for the first three years) per standard bale* of Indian cotton either exported from the country or consumed by the mills. By the Indian Cotton Cess (Amendment) Act, 1947, the cess was made applicable to imported cotton also. By a further amendment of the Act in 1948, the cess of two annas per bale was raised to four annas per bale. From the 1st April, 1951, the provisions of the Indian Cotton Cess Act, which were previously applicable to Parts A and C States only, were extended to Part B States as well.

Besides the income from this cess, the Committee receives, from time to time, special grants from the Government of India's Cotton Fund, built up from the proceeds of the import duty on raw cotton imposed by the Cotton Fund Ordinance (VIII of 1942).

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* 392 lb. net.

The total receipts of the Committee from its inception to the year ending the 31st March, 1957, are shown below:

	Rs.
From Cotton Cess	2,61,24,499
From Cotton Fund	99,94,756
From Miscellaneous Sources	37,54,266
Total ..	3,98,73,521

The annual income of the Committee from the Cotton Cess during the past 10 years, i.e., from 1947-48 to 1956-57, is given below:

	Rs.
1947-48	4,82,244
1948-49	6,58,015
1949-50	9,84,780
1950-51	7,43,329
1951-52	8,25,521
1952-53	10,16,337
1953-54	11,07,353
1954-55	11,45,677
1955-56	12,95,232
1956-57	9,64,553

Mode of Expenditure. The Funds at the disposal of the Committee are allotted for research on cotton problems—agricultural and technological—mainly of all-India importance, and for the development, extension and marketing of improved varieties of cotton in various tracts.

The general policy of the Committee is to give assistance for carrying out co-ordinated research on cotton improvement. This policy is executed through subsidies to the Departments of Agriculture in various cotton growing States for specific investigations on cotton.

Until 1937, the entire expenditure on the various schemes was borne by the Committee, but, in view of the gradual depletion of its reserves owing to annual expenditure exceeding the income, it was decided that the State Governments should accept increasing responsibility for such of the schemes financed by the Committee as, at the end of their sanctioned period, were found to have produced results of definite value. Consonant with its changed policy, the Committee now finances research schemes in full up to a period of 10 years and on a 50:50 basis for the next five years. After these schemes have been in operation for 15 years, the Committee's contribution is stopped altogether and the schemes are taken over completely by the State Governments. The Committee finances in full for a period of 15 years all research schemes aimed at producing cottons of staple 1-1/8″ and above.

The expenditure on seed distribution schemes is divided into: (*i*) cost of staff; and (*ii*) incidental charges on the distribution of seed of approved varieties. The Committee bears either the cost of the staff or the incidental expenditure whichever is less. The seed distribution schemes are sanctioned by the Committee for periods not exceeding five years, in the first instance, but they may be extended subsequently for a further period of five years on the condition that: (*a*) the Committee's share of the expenditure in the second period does not exceed 75 per cent. of either the pay of the staff or incidental expenditure, whichever is less; and (*b*) the State Government concerned contributes not less than the sum spent by it during the original period of the scheme. After seed distribution schemes have been in operation for a period of 10 years, the contribution of the Committee during the next five years is limited to 33 per cent. of the cost of the staff or incidental expenditure, whichever is less, subject to a maximum of 15 per cent. of the total cost of the scheme during the extension period.

The investigations financed by the Committee include:

1. Botanical schemes for breeding high yielding superior types of cotton.
2. Entomological schemes for studying the life history of important cotton pests and measures to control them.
3. Mycological schemes for determining methods to prevent loss due to fungus diseases.
4. Physiological schemes for studying crop growth.
5. Agronomical schemes for determining the manurial and cultural requirements of the crop.
6. Seed multiplication and distribution schemes for the extension of area under approved varieties in demarcated tracts to produce superior cottons of standard purity on commercial scale, as required.
7. Schemes for the extension and marketing of improved varieties of cotton and the maintenance of nucleii of pure seed of approved strains for which the seed multiplication and distribution schemes have ceased to function.
8. Statistical schemes for studying the various factors relating to the collection and interpretation of statistical data.
9. Technological research relating to cotton.

RESEARCH SCHEMES

Since its inception, the Committee has financed 145 research schemes of which 92 have terminated and 53 are in operation now. Among these schemes, those aimed at the genetic improvement of cotton have the pride of place. Investigations financed by the Committee also include entomological and mycological schemes for the study of the insect pests and the pathogenic organisms responsible for the diseases of cotton, and the control measures needed to prevent losses due to these. The physiological schemes were intended for the study of the crop growth and the assessment of the influence of the agro-climatic complex thereon and for the investigation of the physiological malady known as *tirak* (partial failure of cotton) which was the main cause for the deterioration of the crop in the United Punjab and Sind. Physiological work has also been taken up for the investigation of the causes of low yields

in different parts of the country. Thus, cotton research has embraced a very wide field of applied sciences. The results of the various investigations have been dealt with in different chapters of this monograph. The botanical schemes for breeding of high yielding superior types of cotton have yielded strains which during the course of last 35 years have changed the quality of the Indian cotton crop as would be evident from Table 2.

TABLE 2. PRODUCTION OF COTTON ACCORDING TO THE DIFFERENT STAPLE LENGTHS

Year (1st September to 31st August)	Production (thousand bales of 400 lbs. net) based on cotton forecasts			Proportion of long and medium staple cotton to total production (per cent. of column 2 on column 4)
	Staple length 7/8" and above	Staple length below 7/8"	Total all staples	
1	2	3	4	5
Average 1917-22	1,137	3,180	4,317	26
,, 1922-27	1,622	3,827	5,449	30
,, 1927-32	1,327	3,879	5,206	25
,, 1932-37	1,650	3,665	5,315	31
,, 1937-42	2,117	3,480	5,597	38
,, 1942-47	2,649	1,478	4,127	64

N.B.—The figures in the table relate to undivided India

SEED DISTRIBUTION SCHEMES

The Committee recognised as far back as in 1929 that the work of improvement of cotton crop would not be complete without a proper organisation for making the results of research available to the cultivators. It was considered that this would be achieved by distributing pure seed of the improved strains of cotton evolved by the cotton breeders in the various cotton research schemes financed by the Committee, through the medium of seed multiplication and distribution schemes for large scale cultivation in the tract for which they were found suitable. The Committee has been a pioneer body in inaugurating seed multiplication and distribution work of cotton. The pure seed from the breeder is cultivated on a large area on a Government Farm and the entire crop is self-fertilised to maintain cent per cent. purity. This seed is further multiplied on the fields of certain reliable cultivators, chosen by the Agriculture Department in a few villages in the tract. The crop of the cultivators is examined by the departmental officers, rogued (all off-types removed) and the produce ginned under government supervision. The seed is recovered from the cultivators at a small premium over the market rate. The seed is further multiplied in a bigger circle of village plots, and thus in three to

four stages sufficient seed from reserved area is obtained to cover the entire cotton area in the tract. This process of multiplication of the pure seed of improved varieties and extending the area under them has been very successful. The growing of improved varieties has benefitted the cultivator to a very large extent by bringing in better monetary returns than what he could have obtained by cultivating the unimproved types. The gross extra income that has accrued to the cultivators during 1956-57 has been estimated at 13·4 crore rupees (Fig. 1).

A list of the improved varieties evolved under the Committee's schemes is given in Appendix II. The details of the various schemes and methods adopted for seed multiplication and distribution are given in another chapter.

Entomological work undertaken under different schemes financed by the Committee mainly related to the investigation of the life-history of bollworms, white-fly, jassids, black-headed cricket and stem weevil and also to methods of their control. These schemes functioned in the Punjab, Central Provinces and Berar, Uttar Pradesh, Bombay, Hyderabad, Sind, Baluchistan and Madras States.

The pink bollworm which is indigenous to India was found most injurious in Uttar Pradesh. It was found that by heat treatment of the seed it was possible to control infestation. The main method of control of the spotted bollworm, work on which was carried out in Gujerat, was by a systematic uprooting of cotton plants at the end of the season. A suitable plant-puller was designed, and the Committee financed demonstration and subsequent clean-up measures over an area of many square miles. In the case of jassids and stem weevil, it was found that the best means of control lay in breeding types resistant to these pests. Considerable success was recorded in the evolution of resistant types both in the Punjab and Madras where work on these pests was undertaken. The black-headed cricket which was more or less confined to the north-western regions, like Baluchistan and Sind, was found to be controlled best by baiting.

Work on cotton diseases included a very exhaustive study of the two important fungus diseases, cotton wilt and root rot, in Bombay, Baroda, Madhya Pradesh and the Punjab. In the case of wilt, it has been established that the only remedy lies in breeding types resistant to the disease. The Committee has been financing a scheme to test the various types and the breeding material supplied by the cotton breeders, for their relative wilt resistance capacity, at Poona where a special technique for the creation of artificial conditions of infection under optimum conditions has been developed and standardised. Testing under such optimum conditions of infection has yielded very useful results, which have enabled the wilt infected areas to be served by economically high yielding wilt-resistant types.

In the case of root rot, the remedial measure suggested, as a result of exhaustive work in the Punjab, was to intercrop cotton with *moth*, (*Phaseolous*

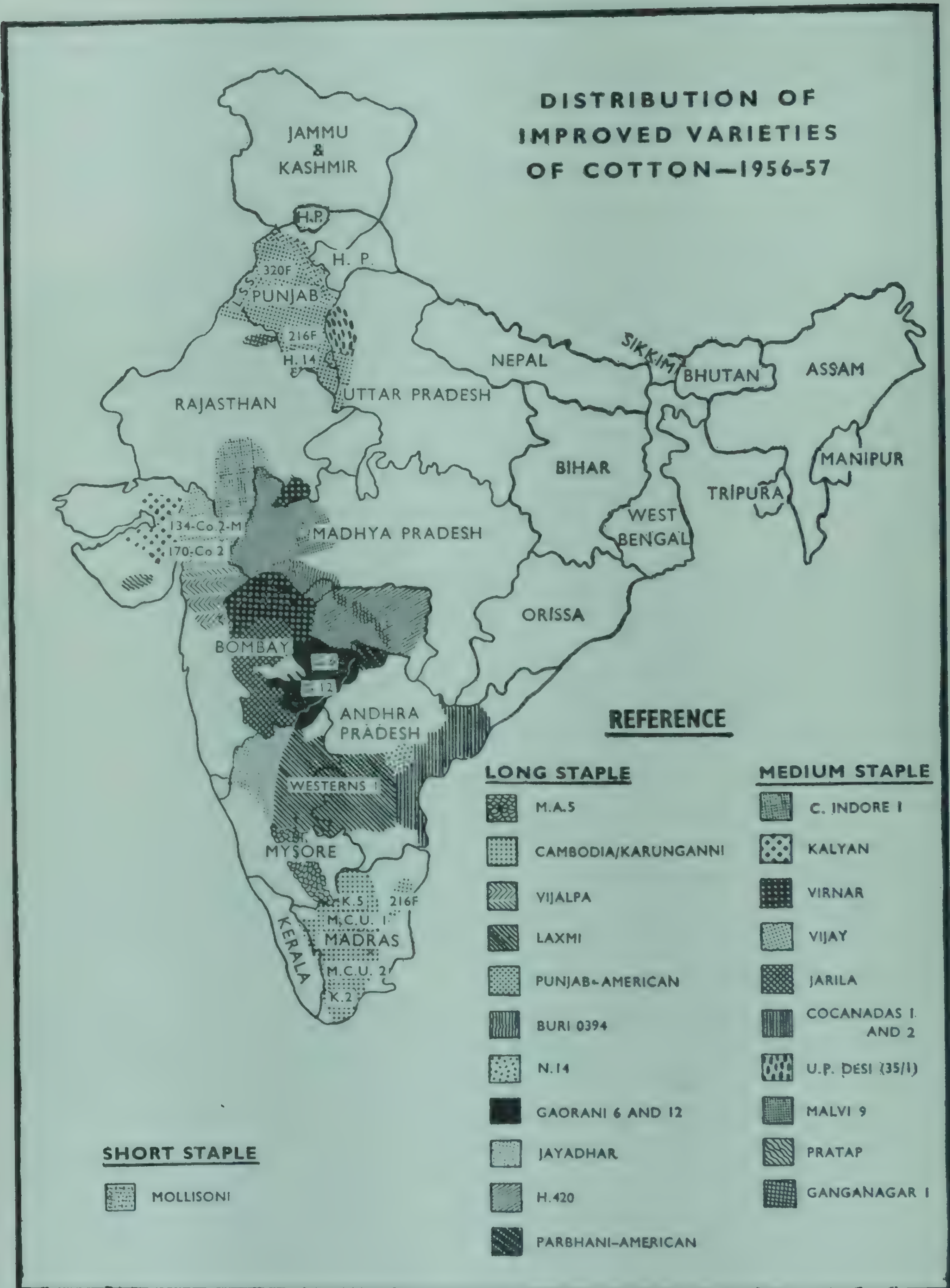

Fig. 1. Distribution of Improved Varieties of Cotton

aconotipholious). It has recently been possible to develop a technique for artificial innoculation and creation of the disease under pot culture conditions at Poona. The work of testing the different types is proposed to be taken up at this centre.

In more recent years, the bacterial disease known as blackarm, which is caused by *Xanthomonas malvacearum*, and the fungus disease anthracnose caused by *Colletotrichum indicum*, have assumed great importance owing to their spread in certain regions. Blackarm is more severe on American cottons, and with the extension of Laxmi, the spread and intensity of the disease have increased a great deal. Anthracnose is a fungus disease, which is particularly conspicuous in parts of Khandesh and Vidarbha. The Committee has been financing a scheme for the breeding of types resistant to blackarm at Dharwar, while seed treatment with a mercurial compound appears to have proved effective for anthracnose in Khandesh. This work is still in progress.

The Committee has also financed investigations on the physiological disease known as *tirak* (partial failure of cotton), which was attributed to two different kinds of soil conditions. As a result of the work done in the Punjab, the remedial measures suggested consisted in recommending special cropping schedules and correcting the soil conditions by manurial and irrigational treatments. The physiological work conducted after the partition of India consisted in studying the causes of low yields of cotton in Madhya Pradesh, Dharwar and Mysore. The work in Mysore, which was mainly intended to find the causes for the low yield of Egyptian cotton, showed that this was primarily due to the inability of the cotton plant to absorb nitrogen, though it was abundantly available in the soil, owing to lack of potash. It was, therefore, found that the application of potash or phosphate or both was a necessary preliminary to the application of a nitrogenous manure to cotton. Another investigation revealed that the low yields in Dharwar area were due to the advanced date of sowing. Shifting the sowings to an earlier date by about a fortnight was found to give 100 lb. more of seed cotton than the yield accruing from the crop sown at the normal time.

The Committee did not restrict its efforts to the production of better cottons but also devoted attention to questions of better marketing, prevention of malpractices in ginning and pressing, and maintenance of the purity of the cotton crop. It may be mentioned in this connection that the Committee has been responsible for the enactment of the various important legislative measures, such as, the Cotton Ginning and Pressing Factories Act, the Cotton Transport Act, the Cotton Control Act, etc., which aim at eliminating all possible chances of the undesirable types getting mixed with the pure strains, preventing the import of short staple coarse types into regions growing long staple finer types, demarcating areas for cultivating specified improved varieties, and prohibiting cultivation of types other than the one approved for cultivation in a particular tract.

It was recognised early that ginning and pressing of cotton needed control, as undesirable mixing and other malpractices like watering, etc., occurred during these processes. For this purpose, identification of the bales and their ownership was considered essential. Legislation was, therefore, enacted for the marking of the bales with approved press marks. Thus, elaborate precautions by way of legislative measures have been taken by the Committee for the maintenance of the purity of the cotton crop in different States. The chapter on Cotton Legislation deals with the different aspects of this part of the Committee's work.

In this connection mention may also be made of the measures taken by the Committee to prevent the introduction of the American cotton boll weevil (*Anthonomous grandis*) into India through imported American cotton. A practical method for satisfactory fumigation of cotton was worked out by the Technological Laboratory in consultation with the Bombay Port Trust, and since 1925 all American cotton was required to be fumigated before landing. The scheme was self-supporting in the sense that the cost was met by a small levy on each bale of American cotton imported.

STATISTICAL RESEARCH

The Committee has devoted particular attention to the collection, compilation and publication of statistics relating to cotton. It has also undertaken investigations for the improvement of cotton forecasts of Bombay State, estimation of the quantity of cotton utilised in the country for such domestic purposes as hand spinning and making quilts, mattresses, padded apparel, cordage, etc., and improving the yield statistics of *kapas*.

TECHNOLOGICAL RESEARCH

The Indian Cotton Committee had recommended that the Central Cotton Committee should have a Cotton Technologist on its staff. Accordingly, the Indian Central Cotton Committee established a Technological Laboratory at Matunga (Bombay) in 1924, where research on cotton technology and the carrying out of comparative spinning tests, the two principal functions for which the Committee was initially set up, were started. The Laboratory is well equipped and possesses a Fibre Testing Section, a Chemistry Section, a Research Section, a Ginning Section, a Microscopy Section, a Pilot Spinning Plant, and a Yarn and Cloth Testing Section.

One of the main functions of the Laboratory is to undertake fibre and spinning tests on samples of cotton supplied either by the Agriculture Departments or the trade or the mill industry, and to issue reports embodying results of such tests. The necessity for making tests on agricultural samples arise from the needs for assessing under known and reproduceable conditions the fibre properties and spinning performances of improved varieties of cotton before they can be recommended for general cultivation. The Technological

Laboratory has helped the cotton breeders in all the States in assessing the spinning capacity of each of their strains and enabled them finally to select the improved varieties.

In the Ginning Section, experiments have been undertaken by the Laboratory to test the efficacy of the different types of gins. A notable achievement of this Section is the fabrication of a small roller gin for use at the research stations for ginning small quantities of plant produce.

The Fibre Testing Section does a volume of work in assessing the staple length, the fibre strength and various other individual characters of the fibre from different samples received from the cotton breeders.

The Spinning Section is the most important section, and has a pilot plant for spinning small samples of cotton (up to a limit of 12 lb. lint) into finished yarn of different counts, following exactly the same processes as employed in a full fledged textile mill. By this method the Laboratory has been able to adjudge the suitability of the various new strains of cotton evolved by the cotton breeders in regard to their spinning performance. The cotton breeders invariably depend upon these test results for making final selection of cotton strains.

The Laboratory also arranges, in co-operation with the textile mills, tests in the mills with a view to determining the spinning value of different cottons under mill conditions.

It also undertakes tests on various trade varieties which are marketed as well as on standard Indian cottons which are in the process of being given out for general cultivation on a large scale, and publishes the results in Technological Bulletins.

To facilitate testing of the larger number of samples available with the breeders, the Committee has stationed Technological Assistants at different centres like Abohar (Punjab), Indore, Nagpur, Nanded, Surat, Dharwar and Coimbatore. The work of these Technological Assistants is co-ordinated by the Director, Technological Laboratory.

Since January, 1940, the Laboratory has been imparting annually training in the various fibre and yarn testing methods for a period of six months. In addition, a short term training course lasting for about three weeks is also given to the employees engaged in the ginning and pressing factories.

The assistance rendered by the Laboratory to the cotton breeders could be gauged from the fact that while in 1922-27 the long staple cottons constituted only 13 per cent. of the total cotton production in India, in 1956-57 it formed 41 per cent. of the production.

Another main item of work done at the Technological Laboratory is the correlation of fibre properties with spinning performance. The fluctuations in the spinning performance of several Indian cottons have also been investigated, and it has been demonstrated that more often than not, the apparent

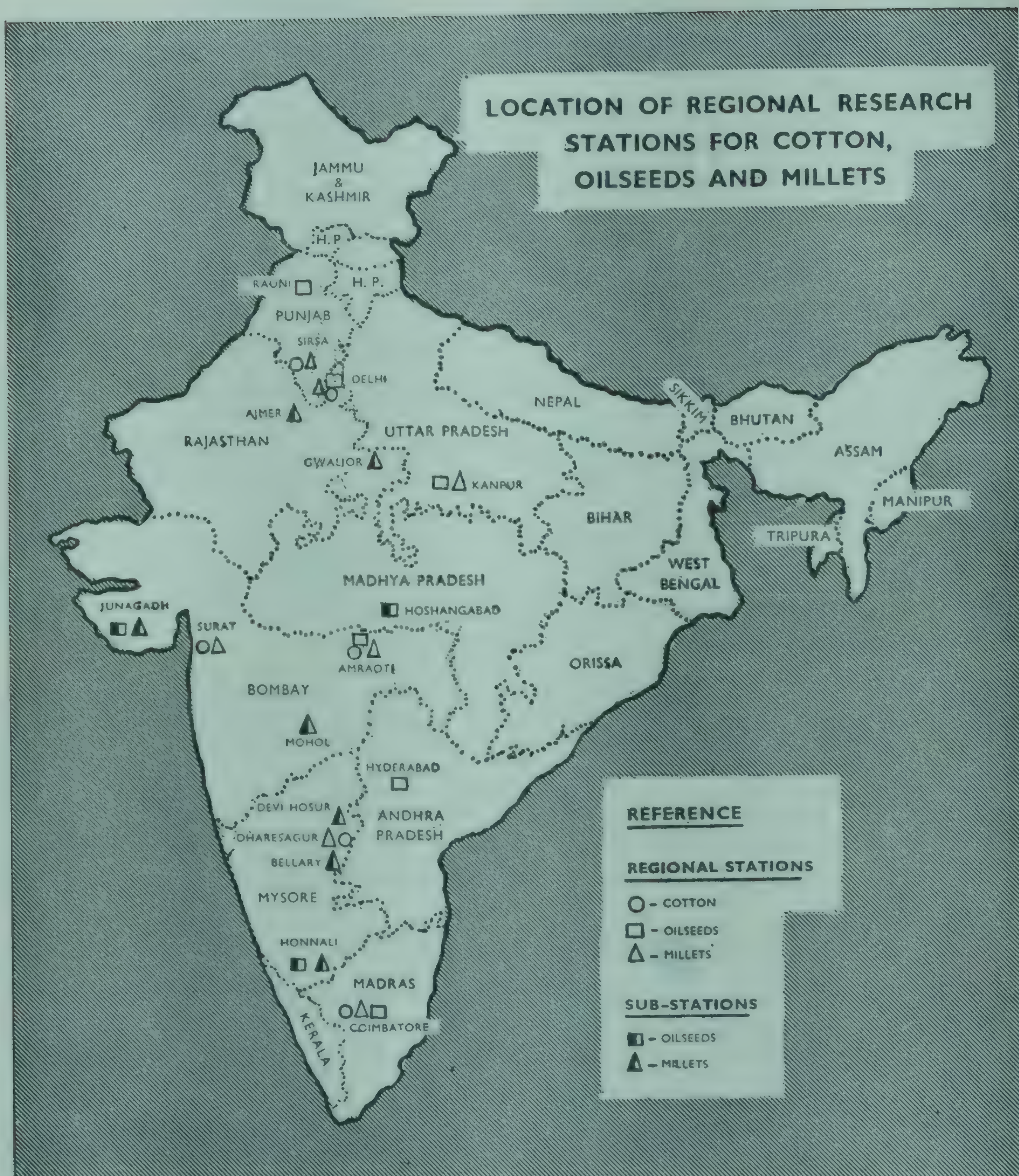

Fig. 2. Location of Regional Research Stations for Cotton, Oilseeds and Millets

fall in the performance is due more to seasonal factors and physical admixture of different varieties than to any real genetic deterioration. Several problems connected with the storage and handling of cottons have also been investigated. The test results on the standard cottons and the commercial types of each season are made available to the cotton trade both in India and abroad. A number of tests have also been carried out on samples of improved varieties grown under different conditions of irrigation, spacing, time of sowing, rotation of crops, combinations of manures and fertilisers, etc.

In 1937, the Laboratory was recognised by the Bombay and Ahmedabad Millowners' Associations as their official Testing House for the testing of cottons, yarns, piecegoods, textile auxiliaries, artificial silk yarns, etc., and for the issue of authoritative reports on them. In 1939, the Bureau International Pour La Standardisation Des Fibres Artificiells (B.I.S.F.A.) also recognised the Laboratory as its Testing House for artificial silk yarns and cloths. In 1940, a Ginning Section was added to the Laboratory with the object of making investigations to improve the ginning of Indian cottons.

Regional Research Stations. As detailed in the previous pages, the policy of the Committee has been to subsidise schemes for research or seed multiplication and distribution, sponsored by the State Governments. While this policy has worked successfully, it has been felt that more work has to be done in the field of fundamental research. For meeting this need, the Committee in collaboration with the Indian Council of Agricultural Research and the Indian Central Oilseeds Committee has considered a scheme for the establishment of co-ordinated research on cross-commodity basis and decided to finance projects for the intensification of regional research on cotton, oilseeds and millets. Work on cotton is proposed to be undertaken at six centres: Sirsa (Hissar) in the Punjab; Indian Agricultural Research Institute, New Delhi; Surat, and Amravati, in Bombay State; Dharesagur in Mysore State; and Coimbatore in Madras State (Fig. 2).

REBIRTH OF INDIAN TEXTILE INDUSTRY

A new era in the production of textiles began with the introduction of machines. The year 1814 is an important landmark in the history of Indian textile industry, for it was in that year that the first textile mill in the country was established. It was set up on the banks of the Hoogly through the enterprise of an Englishman. Subsequently, in 1843, another textile mill was established in Broach. The first textile mill in Bombay was put up in 1854. Since then the textile industry has been expanding, and today it is one of the best organised industries in the country.

There are, at present, 465 textile mills in India of which 212 are concentrated in Bombay State. A comprehensive account of the textile mills together with details of spindles, looms, yarn and cloth production is given in

Appendix III. From 1954 to 1956 the exports of textiles and cotton yarn from India amounted to Rs. 66 crores on an average.

The industry, besides supporting the cultivator and the handloom weaver directly, engages 8,06,700 operatives, whose earnings amount to over Rs. 100 crores a year. It also provides employment to a large number of people engaged in the manufacture of textile auxiliaries and other subsidiary industries. Besides, the Excise Duty on mill cloth brings to the Exchequer Rs. 20 crores annually. The importance of the textile industry in the economy of the country is, thus, self-evident.

RECENT TRENDS IN COTTON PRODUCTION

The total production of cotton in undivided India in 1938-39 was about 59 lakh bales. Against this, the consumption by the spinning mills in the country amounted to 31·5 lakh bales of Indian cotton (including about eight lakh bales of cotton from the territories now included in Pakistan) and 6·6 lakh bales of foreign cotton. This left a surplus of nearly 28 lakh bales, which were partly carried forward as stock and partly exported. During the Second World War, and more particularly after the entry of Japan into it in December, 1941, the export markets for short staple cottons were lost, making cotton a drag on the market. Special measures were then taken to curtail its production. These efforts were intensified a year later when the food position in the country deteriorated a great deal. As a result, the annual production of cotton in undivided India was brought down to 42 lakh bales in 1945-46. Practically the whole of this reduction took place in the territories now comprising the Indian Union. Out of the total area of 1,48,60,000 acres in 1946-47, the area covered by improved varieties amounted to 55 per cent., which in terms of acreage distribution between the areas now included in the Indian Union and Pakistan came to 45 per cent. and 89 per cent., respectively. On the partition of the country in 1947, about 10 lakh bales of good quality cotton produced annually in the irrigated tracts of Sind and the West Punjab and consumed by the Indian mills, were suddenly lost to the country. In other words, as a result of the partition, slightly less than 1/4th of the total area and over 4/5th of the area under irrigated cotton in undivided India went to Pakistan. The position is indicated in Table 3.

It will be seen from Table 3 that the Indian Union's share of undivided production of cotton of staple length 7/8″ and above, below 7/8″ and above 11/16″, and 11/16″ and below, constituted 45, 62 and 76 per cent., respectively.

As regards cotton of staple length 1″ and above, it may be mentioned that production in the Indian Union and Pakistan amounted to one and two lakh bales, respectively. Thus, while the supply position deteriorated, the demand for raw cotton remained almost unaffected because 98 per cent. of the textile mills of undivided India were situated in the Indian Union. The

TABLE 3. PRODUCTION OF COTTON IN INDIA AND PAKISTAN (1946-47)

Staple length		Cotton Production (lakh bales of 392 lbs. net each)		
		Undivided India	Indian Union	Pakistan
7/8″ and above	Actual	9·9	4·5	5·4
	Per cent.	*33*	*17*	*34*
Below 7/8″ and above 11/16″	Actual	20·9	13·0	7·9
	Per cent.	*50*	*50*	*49*
11/16″ and below	Actual	11·2	8·5	2·7
	Per cent.	*27*	*33*	*17*
Total ..	Actual	42·0	26·0	16·0
	Per cent.	*100*	*100*	*100*

mill consumption accounted for 38·6 lakh bales of a total consumption of 39·4 lakh bales in undivided India. Details of the Indian Union's mill consumption of cotton classified by staple length are given in Table 4.

TABLE 4. MILL CONSUMPTION OF COTTON IN THE INDIAN UNION

Staple length	Mill Consumption (lakh bales of 392 lbs. net each)			
	Indian cotton	Pakistan cotton	Other foreign cotton	Total all cotton
7/8″ and above	3·9	4·2	7·0	15·1
Below 7/8″ and above 11/16″	12·5	5·6	—	18·1
11/16″ and below	5·4	—	—	5·4
Total ..	21·8	9·8	7·0	38·6

It will be seen that at the level of consumption in 1946-47, the Indian Union was dependent on Pakistan cotton to the extent of 9·8 lakh bales (4·2 lakh bales of staple length 7/8″ and above and 5·6 lakh bales of staple length below 7/8″ and above 11/16″) and other foreign cotton to the extent of seven lakh bales (mostly 1″ and above in staple). The net result was that the country had to import nine lakh bales of medium and long staple cotton from Pakistan and six to seven lakh bales of quality cottons from the East Africa, the Sudan, Egypt, etc.

The problem immediately after the partition was two-fold:

1. To produce enough cotton in the country of the types comparable to Pakistan varieties so that India might become independent of the supplies from that country as early as possible.
2. To breed extra-long staple cotton varieties suited to Indian conditions, so that eventually the country might be able to grow them in adequate quantities to meet the internal requirements and eliminate imports from abroad.

The policy of the Indian Central Cotton Committee came to be directed towards serving this dual need.

Grow-More-Cotton Campaign. The problem of keeping the entire Indian textile industry fully engaged was tackled with a determination and speed unique in the history of Indian agriculture. A Grow-More-Cotton Campaign was launched side by side with the campaign for increasing food production. The food problem naturally had precedence over the cotton problem, and this was a limiting factor in pushing up cotton production.

Short-Term Policy for Increasing Production. The serious position arising from the diversion of land from cotton to food and groundnut crops, the partition of the country, and the devaluation of the currency accompanied by high increase in the rupee price of foreign cotton was considered by the Indian Central Cotton Committee at its meeting held in October, 1949. It was recommended that the country should become self-sufficient in respect of cotton of staple length 1" in as short a period as possible, and that the cotton production in 1950-51 should be increased by about 10 lakh bales (as compared with the production in 1949-50).

To achieve the objectives, the Committee recommended the following measures:

1. Every attempt should be made to increase the production by raising the yield per acre and by utilising fallow lands for cotton, wherever possible.
2. In view of the difficult food position of the country, only the minimum acreage should be diverted from food grains to cotton.
3. Where such diversion is inevitable, the Central Government should guarantee to make good to the State Governments the short-fall in food grains.
4. The Government of India should give the same high priority to the growing of more cotton as the growing of more food and should make available the required staff and funds to increase production by such aids as fertilisers, improved seed, implements (including power implements), priority of transport, irrigation facilities, etc.
5. In order to make cotton growing more attractive to the grower, the price of groundnut (the most serious competing crop) should be controlled in the same manner as that of cotton.

In consideration of the recommendations of the Committee, a target of 5·97 lakh bales of additional production was fixed by the Government of India for 1950-51, and the following concrete steps were taken by the Central and State Governments:

1. All legislative and executive restrictions on the growing of cotton were removed by the State Governments and wide publicity was given by them to the removal of such restrictions.
2. Additional irrigation facilities for the growing of cotton were provided wherever possible.
3. Remission of land revenue was allowed in respect of additional area brought under cotton cultivation.
4. The Central Government gave a guarantee to the State Governments to make good the short-fall in food grains caused by the diversion of land from food crops to cotton.
5. Supplies of improved seeds and fertilisers were made on a large scale at subsidised rates, and wherever necessary, funds were loaned to the State Governments for their bulk purchases.
6. Special staff was appointed in all cotton growing States for the execution of the plan.

7. The basic ceiling prices of all varieties of cotton for the season 1950-51 were increased by Rs. 150 per candy (784 lb. of lint) in comparison with the controlled prices fixed for them in the previous year.

For the implementation of the above measures, the Government of India sanctioned a grant of Rs. 15·24 lakhs and a loan of Rs. 27·32 lakhs to the various State Governments.

Cotton Extension Schemes. The Cotton Extension Schemes sponsored by the Government of India came into being and envisaged an increase of 5·97 lakh bales for 1950-51 over the production in 1949-50, raising the total production to 35·68 lakh bales. The targets of additional area and production and the additional production reported to have been achieved at the end of the season are shown in Table 5.

TABLE 5. TARGETS OF COTTON PRODUCTION AND ACHIEVEMENTS (1950-51)

	Targets		Estimated Achievements	
	Additional area (lakh acres)	Additional production (lakh bales of 392 lbs. net)	Additional area (lakh acres)	Additional production (lakh bales of 392 lbs. net)
A. By expansion of area	19·87	4·57	15·99	3·11
B. By intensive cultivation				
(i) By irrigation	0·93	0·08	0·98	0·09
(ii) ,, use of improved seed	10·02	0·25	10·00	0·23
(iii) ,, application of fertilisers.. ..	4·65	0·29	2·00	0·10
(iv) ,, intercropping of cotton with other crops	14·49	0·78	1·23	0·08
(v) ,, adopting improved cultural methods	—	—	0·09	0·02
Total A and B ..	—	5·97	—	3·63

Figures of area against items B (*i*) to B (*v*) represent the area to which intensive cultivation measures were proposed to be or have been applied.

Owing to the unfavourable seasonal conditions prevailing in 1950-51, the increase of production was only 3·63 lakh bales against the target of additional production of 5·97 lakh bales. The Government of India in consultation with the State Governments decided to continue the Grow-More-Cotton Campaign and laid down plans for increasing further the production in the succeeding years. This scheme involved :

1. The increase of the area under medium and long staple varieties by about four million acres spread over different Provinces and States.
2. The replacement of short staple cotton by medium and long staple varieties in the irrigated cotton tracts of the East Punjab and the Patiala and East Punjab States Union and in some of the heavy rainfall areas of Hyderabad State.
3. The increase of the yield per acre, particularly of irrigated cotton, by greater use of fertilisers.
4. The provision of greater irrigation facilities through minor irrigation works for the growing of good quality cotton.

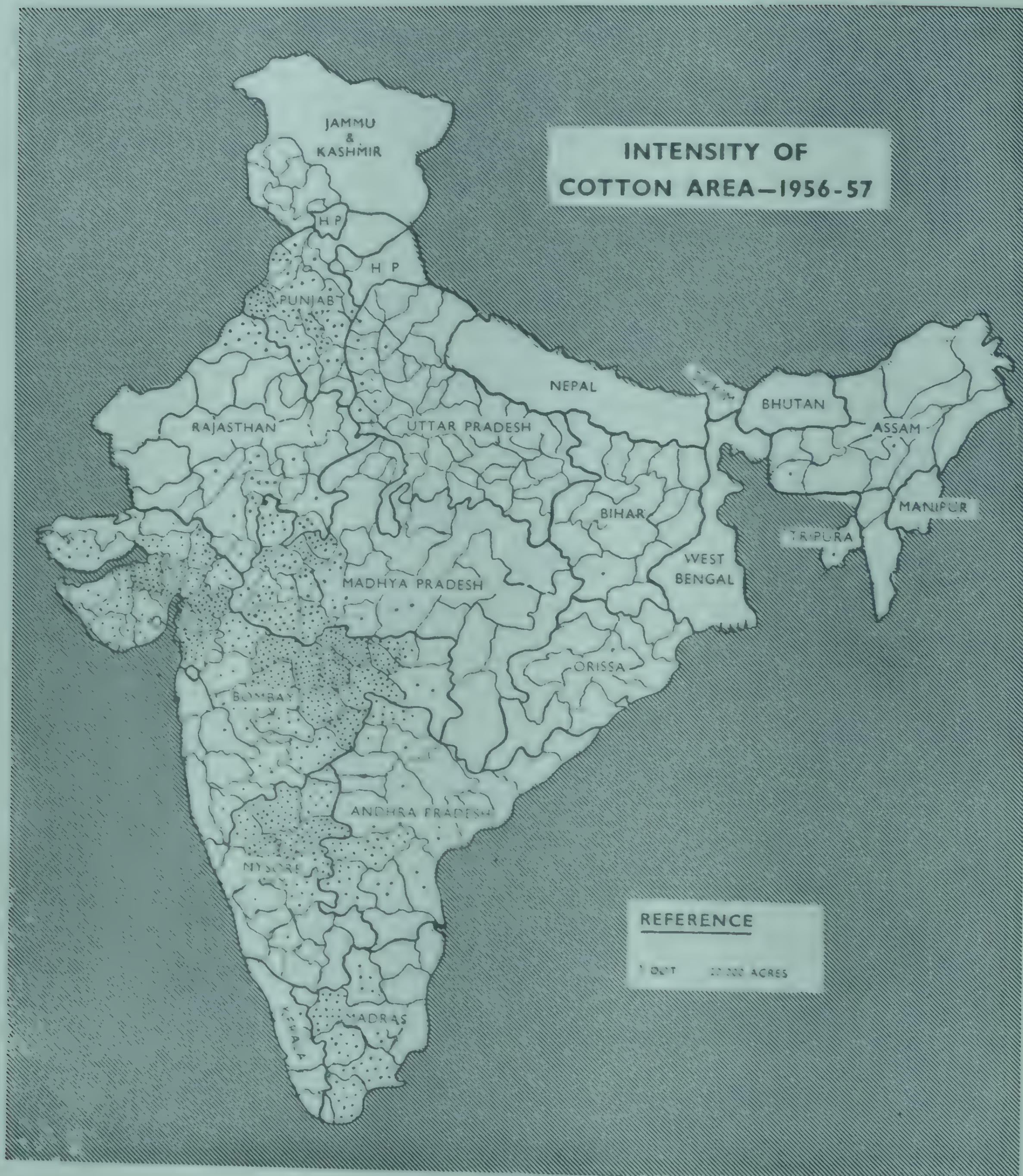

Fig. 3. Intensity of Cotton Area in different parts of India

Subsequently, the production of cotton was merged with the targets fixed by the Planning Commission for the First Five-Year Plan. The Statewise figures of area and production of cotton during the five years are shown in Tables 6 and 7 (Fig. 3).

TABLE 6. AREA UNDER COTTON (1950-51 TO 1955-56)

State	1950-51	1951-52	1952-53	1953-54	1954-55	1955-56
Andhra Pradesh	1,413	1,538	1,084	1,198	1,218	1,195
Assam	30	34	38	38	35	35
Bihar	15	14	13	12	12	11
Bombay	6,879	8,174	8,415	9,284	9,908	10,869
Kerala	18	16	15	17	19	22
Madhya Pradesh	1,925	1,837	2,073	2,107	2,356	2,324
Madras	710	840	692	813	823	921
Mysore	2,321	2,299	1,958	2,283	2,449	2,798
Orissa	24	27	26	26	25	25
Punjab	693	822	809	898	1,189	1,282
Rajasthan	378	380	358	427	509	590
Uttar Pradesh	106	193	207	140	120	136
West Bengal	(*a*)	3	2	1	(*a*)	(*a*)
Delhi and Himachal Pradesh	1	2	1	1	1	1
Tripura	23	22	22	20	20	21
Total ..	14,536	16,201	15,713	17,265	18,684	20,230

(*a*) Less than 500 acres.

TABLE 7. PRODUCTION OF COTTON (1950-51 TO 1955-56)

State	1950-51	1951-52	1952-53	1953-54	1954-55	1955-56
Andhra Pradesh	171	221	135	118	158	140
Assam	12	14	17	19	8	8
Bihar	3	3	4	1	1	2
Bombay	1,439	1,468	1,537	2,018	2,226	1,923
Kerala	6	6	6	8	8	9
Madhya Pradesh	268	261	393	419	433	419
Madras	214	281	201	257	256	282
Mysore	305	315	282	378	353	433
Orissa	2	2	2	2	2	2
Punjab	310	400	436	554	613	605
Rajasthan	125	89	101	118	126	163
Uttar Pradesh	45	63	70	44	34	27
West Bengal	(*b*)	1	1	(*b*)	(*b*)	(*b*)
Delhi and Himachal Pradesh	1	1	1	(*b*)	(*b*)	(*b*)
Tripura	9	8	8	8	9	7
Total ..	2,910	3,133	3,194	3,944	4,227	4,020

(*b*) Less than 500 bales.

The staplewise distribution of area and production of cotton during the First Plan period is shown in Tables 8 and 9.

TABLE 8. DISTRIBUTION OF COTTON AREA* (1950-51 TO 1955-56)

Staple length group	1950-51	%	1951-52	%	1952-53	%	1953-54	%	1954-55	%	1955-56	%
Long staple (7/8" and above)	3,416	23	4,839	30	4,521	29	5,945	34	6,080	33	6,965	35
Medium staple (below 7/8" and above 11/16")	7,563	52	7,071	44	7,448	47	7,600	44	8,684	47	9,313	46
Short staple (11/16" and below)	3,577	25	4,288	26	3,724	24	3,637	22	3,920	20	3,952	19
Total ..	14,556	100	16,198	100	15,693	100	17,182	100	18,684	100	20,230	100

* Thousand acres.

N.B.—Distribution of area under different groups according to revised figures given on page 35 is not available.

TABLE 9. STAPLEWISE PRODUCTION OF COTTON* (1950-51 TO 1955-56)

Staple length group	1950-51	%	1951-52	%	1952-53	%	1953-54	%	1954-55	%	1955-56	%
Long staple (7/8" and above)	684	23	918	29	905	29	1,442	36	1,529	36	1,577	39
Medium staple (below 7/8" and above 11/16")	1,448	49	1,223	39	1,395	44	1,651	42	1,908	45	1,781	44
Short staple (11/16" and below)	839	28	992	32	831	27	872	22	790	19	662	17
Total ..	2,971	100	3,133	100	3,131	100	3,965	100	4,227	100	4,020	100

* Thousand bales of 392 lb. each.

N.B.—Distribution of production under different groups according to revised figures given on page 35 is not available.

As compared to 1950-51, the total production of cotton increased during the Plan period by 35 per cent. and that of long and medium staple varieties by 131 and 23 per cent., respectively. On the other hand, the production of short staple cotton decreased by 21 per cent. Thus a major shift was registered towards producing finer and long staple varieties.

The targets of additional area and production of cotton fixed for 1955-56 season, the last year of the First Plan period, under the different measures of the Cotton Extension Schemes, together with the estimated achievements are shown in Table 10.

It will be seen that the measures taken for increasing the production of cotton have met with remarkable success. The area exceeded the anticipated figure of 18 million acres by 11 per cent. due to favourable weather conditions at sowing time. The production was, however, lower than the target by about five per cent. on account of adverse climatic conditions later in the season.

Long-Term Policy. Though the deficit in the supply of Pakistan varieties of cotton required by cotton textile mills was made up, there was still

TABLE 10. TARGETS AND ACHIEVEMENTS UNDER COTTON EXTENSION SCHEMES (1955-56)

Particulars	Additional Area Targets	Additional Area Achievements	Additional Production Targets	Additional Production Achievements
A. By expansion of area	5·85	12·42	1·26	2·41
B. By intensive cultivation measures ..				
(i) By provision of irrigation facilities..	1·85	3·84	0·44	0·97
(ii) ,, intercropping of cotton with other crops	4·31	3·78	0·42	0·30
(iii) ,, manuring	3·89	1·69	0·28	0·08
(iv) ,, use of improved seed	38·27	47·69	0·41	0·45
(v) ,, plant protection measures ..	0·82	0·06	0·04	—
(vi) ,, improved cultural methods ..	0·03	0·52	0·01	0·03
Total ..	—	—	2·86	4·54**

** Includes 0·3 lakh relating to the Punjab ; details not available.

need for stepping up the production of cotton to meet the increasing requirements of the textile industry on account of rising standards of living and the likely increase in population. It was, therefore, proposed that a higher target of production should be fixed for the Second Plan period. The Planning Commission fixed a target of 55 lakh bales to be achieved by 1960-61. As this was considered inadequate, it was raised to 58·58 lakh bales at a Conference of the State Ministers of Agriculture. Subsequently, the Indian Central Cotton Committee expressed the view that the target should be further increased to 65 lakh bales. This target was ultimately accepted by the Planning Commission after further discussions with the States.

Increasing the area under irrigated cotton offered a good scope for raising the yield per acre. At present, this area is about 10 per cent. of the total acreage and it is expected that the various irrigation-*cum*-hydroelectric projects after completion would add another 1·3 million acres, bringing the total irrigated area to 3·2 million acres.

Since cotton is grown in India mainly under rainfed conditions, use of improved seed, adoption of plant protection measures, and employment of improved cultural methods would have to be depended upon principally for raising the acre yields. The use of fertilisers for increasing production will also have to be extended especially in areas receiving irrigation or assured rainfall.

In spite of the various efforts made in recent years to increase cotton production in the country, the Indian textile industry has still to depend for supplies of fine and superfine cloth on extra-long staple cottons produced in other countries, though as may be seen from Table 11, the progress in cotton breeding is tending to reduce this dependence.

There is still a gap of nearly six lakh bales of superior quality cottons which are not being produced in this country. There is, however, a possibility

TABLE 11. MILL CONSUMPTION OF COTTON IN INDIA*

Year		Total	Indian cotton		Foreign cotton	
			Consumption	Per cent. to total	Consumption	Per cent. to total
1951-52	..	4,071	2,987	73·4	1,084	26·6
1952-53	..	4,460	3,611	81·0	849	19·0
1953-54	..	4,608	3,889	84·4	719	15·6
1954-55	..	4,769	4,138	86·8	631	13·2
1955-56	..	4,969	4,366	87·9	603	12·1

* Thousand bales of 392 lbs. each.

of covering the deficit by about 50 per cent. from indigenous production, provided the strains now under different stages of trial prove successful.

In addition to the breeding of extra-long staple cottons from the acclimatised American cottons in Madras, the Punjab and Bombay, attempts have also been made to investigate the possibility of acclimatising and economically cultivating the Sea Island cottons of the West Indies on the West Coast of India. The first few years were spent in adjudging the suitability of the Sea Island varieties for cultivation in Kerala, where little or no cotton was grown, and in studying the conditions conducive to high yields of the variety 'Andrews' finally selected for cultivation. The experiments in 1954-55 indicated that with proper interculture, manuring and adoption of plant protection measures a highly remunerative yield could be obtained. A co-ordinated scheme for the cultivation of Sea Island 'Andrews' cotton in the States of Kerala, Mysore and Assam has been approved by the Government of India, and it is progressing under the *aegis* of the Indian Central Cotton Committee. During 1957-58, the variety has been grown on the cultivators' fields in 24 primary centres spread over in the States concerned, covering an area of some 130 acres. The progress of the crop is watched with great interest.

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CHAPTER II

CLIMATE AND SOILS

The two most vital factors governing the cultivation of cotton, as that of other crops, are climate and soils. The former is even more important than the latter, for the soil types existing in a region are mainly the result of the action of climate on the parent rocks. No human endeavour can fully counterbalance an unsuitable climate. The cotton plant is uncommonly sensitive to the vagaries of weather. Continuous rains or a long spell of dry weather may prevent the sowing of the crop at the proper time, hinder seed germination, or retard crop growth. Heavy rains, continuous high winds or excessive drought at flowering and fruiting time may cause heavy shedding of buds and young bolls, thereby ruining the crop. An early frost may kill the plants prematurely. Untimely rains and a heavy humid weather during the later stages of the cotton season may spoil the produce, lower its spinning properties, or promote the attack of pests and diseases. Thus the success or failure of the cotton crop in a locality is intimately bound up with the prevailing weather conditions.

India lies between 8° to 36° North latitude, and so practically the whole country, excepting Jammu and Kashmir, is located within the natural habitat of the cotton plant. Perennial cottons are also found practically all over the country. Subject to adequacy of rains and suitability of soil, cotton is grown in varying degrees in practically all parts, i. e., from the Punjab to Cape Comorin and from Kutch to Assam. Its cultivation is, however, more extensive in the relatively drier parts. Nearly 90 per cent. of the total annual acreage under the crop is accounted for by Peninsular and southern India, comprising Bombay, Madhya Pradesh, Andhra Pradesh, Mysore and Madras. In the north, it is cultivated largely in the Punjab, Rajasthan and western Uttar Pradesh, and to a very limited scale in Assam hills. It is not of much importance in the heavy rainfall rice growing States of Bihar, Orissa, Bengal, Assam and Kerala, nor in the extremely dry unirrigated and arid tracts of western Rajasthan. However, the growing of cotton under heavy rainfall conditions in Assam hills is possible on hill slopes which are not subject to water-logging.

CLIMATIC REQUIREMENTS

In its wild state, cotton grows as a perennial plant in the drier and more open parts of the tropics and the sub-tropics. Being a native of warm climate, the natural limit for its successful cultivation is set by the conditions associated with such tracts. The climatic requirements for the successful cultivation of cotton are : (*i*) a mean annual temperature of over 60° F.;

(*ii*) an annual rainfall of at least 20″ with favourable distribution ; (*iii*) abundant sunshine during the period of boll maturation and harvesting of the produce ; and (*iv*) a frostless season of 180 to 240 days in North India. The cotton plant cannot stand frost, and its cultivation is restricted largely to flat or undulating country up to an altitude of 3,000 feet.

Of the different climatic factors that influence the cultivation of cotton in India, rainfall and temperature are the most important. The incidence of rainfall alone, i.e., the quantity and its distribution during the successive stages of plant development, account for 60 to 70 per cent. of the annual fluctuation in the Indian cotton production. Adequate soil moisture is necessary during all stages of crop development. Excessive as well as inadequate soil moisture affects the crop adversely. As regards temperature, successful seed germination requires a daily minimum temperature of 60°F. and above. For good plant growth, cotton generally requires a rather high and uniform temperature. The optimum temperature range for vegetative growth is 70° to 80°F. On the other hand, at Surat in Bombay State, the period of relatively wider divergence between daily and miximum and minimum temperatures has been found to synchronize with the period of maximum plant growth. Continued heavy rains immediately after sowing produce a water-logged condition and retard plant growth in this tract. During the period of fruiting day temperatures of 80° to 90°F. and cool nights are needed for the best results. For harvesting of good quality produce, bright sunny days are essential. Given good moisture conditions, the cotton plant can stand even temperatures as high as 110° to 115° F. However, under conditions of high air temperatures, irrigation of the crop is necessary (Fig. 4).

In India, cotton is cultivated largely in the States of Bombay, Andhra Pradesh, Madras, Mysore and Madhya Pradesh in the south and the Punjab, Rajasthan, western Uttar Pradesh and (to a small extent) Assam in the north. The seasons in general differ in these two regions. In North India, there are four distinct seasons : (*i*) summer (March to May), characterised by high temperatures, hot winds and dry weather ; (*ii*) monsoon (June to September), the season of maximum rainfall and humidity, cloudy skies and moderate day temperatures ; (*iii*) dry post-monsoon season (October to November), when, compared to summer, the days are shorter, and both maximum and minimum temperatures lower, with fine dry weather and early morning mists ; and (*iv*) winter (December to February) which is cold and dry, with frequent early morning mists, occasional frost in certain areas, and snowfall in the hills. In South India, there are only three main seasons : (*a*) warm wet (June to October) season, generally characterised by a warm and humid climate and maximum rainfall ; (*b*) cool dry (November to February) season when temperatures and humidity are low ; and (*c*) hot dry (March to May) season with high temperatures, hot winds and dry conditions.

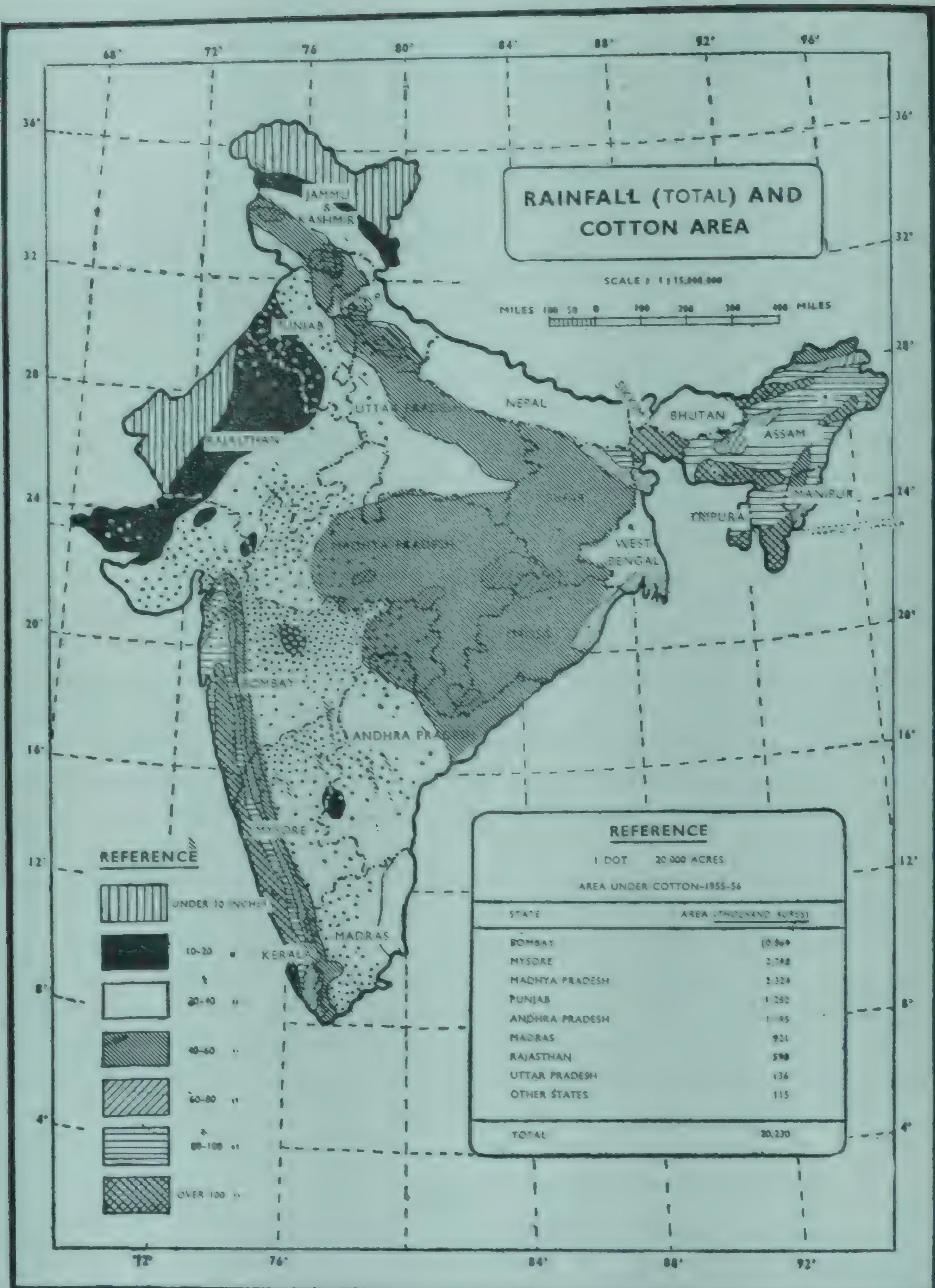


Fig. 4. Distribution of Rainfall and Area under Cotton

In almost all parts of India, most of the rainfall is received through either the south-west or the north-east monsoon. The north-east monsoon lasts from December to February when the skies are clear with fine weather, greater sunshine, low humidity and temperature and large diurnal variation of temperature. In general, temperature is the lowest in the north-west, and increases eastwards and southwards. Precipitation is greatest in the north-west and generally decreases eastwards and southwards, and again increases in the extreme south-east due to the proximity of the Bay of Bengal. The south-west monsoon continues from June to September and generally bursts on the Malabar coast during the first week of June, gradually extending northwards and finally establishing itself over most parts of the country by the end of June. The monsoon is never continuous but has frequent breaks. The rainfall normally increases from June to July and remains steady till about the end of August after which it starts retreating from North-west India (Punjab) in the third week of September. The distribution of rainfall received through the north-east and the south-west monsoons is shown in Figures 5 and 6.

In general, Indian agriculture depends largely on monsoon and 85 per cent. of the total rainfall is derived from it. Usually the rain is not continuous during monsoon. Sometimes the breaks may be lengthy and the precipitation reduced appreciably resulting in crop failure. Since 93 to 94 per cent. of the total cotton area is grown under rainfed conditions in the country, monsoon is of great significance for the successful cultivation of the crop.

According to Chatterjee (1954) an annual rainfall of between 20 and 100 inches is favourable for agricultural use, while semi-arid areas with 10 to 20 inches of rainfall are suitable only for grazing and dry farming except where irrigation facilities are available to supplement the deficiency. Areas with rainfall below 10 inches usually have desert conditions unless water for irrigation is available from other neighbouring areas. The distribution of rainfall and the percentages of land area under each class are given in Table 12.

TABLE 12. DISTRIBUTION OF PRECIPITATION IN INDIA*

Annual rainfall (inches)	Percentage of land area	Climatic classification
Under 10	9·1	Arid
10-25	15·6	Semi-arid
26-50	42·7	Sub-humid
51-75	20·1	Humid
76-100	5·0	Wet
Over 100	7·5	Very wet

* Chatterjee, S. B., 1954 : Indian Climatology, Climate Classification of India, Commercial Printers, Calcutta-6.

The climate varies greatly in different States and also within the same State. Extreme variations in climate with very high summer temperatures, severely low temperatures and moderate rainfall (15"–30") with occasional frost and snowfall (in hills) during winter occur in the Punjab, western Uttar Pradesh and eastern Rajasthan. Whereas in Bihar, West Bengal, eastern Uttar Pradesh, Orissa, northern and eastern Madhya Pradesh, and parts of Assam and Tripura the rainfall is heavy (50"–90" and above) which is received mainly during June to September with occasional rains in December-January. However, in West Bengal two-thirds of the rains are received during March to October. In general, this region is characterized by high humidity (80%–85%) and alternate dry and wet seasons. In most of the major cotton growing tracts in Peninsular and South India, such as, Bombay (Saurashtra, Khandesh, and eastern Bombay), Madhya Pradesh, Andhra Pradesh, Mysore and Madras, the rainfall is moderate (20"–50"), mostly received through the south-west monsoon, except in Madras and parts of Mysore where about one-third of the rainfall is received through the north-east monsoon in October-November. The maximum summer temperatures vary from 90° to 118° F. and the minimum winter temperatures range between 30° and 70° F. in different parts of this region. Arid climatic conditions receiving very low rainfall (about 20") are found in certain areas like western Rajasthan and Kutch (Bombay State) which have low lying lands. In this region, the summer temperatures are high with fairly low winter temperatures (Table 13).

Rainfall. The rainfall varies widely from 3 to 450 inches in different parts of India. In general, the annual rainfall is highest (over 100") in certain areas of the western coastal region and Assam hills. The heaviest precipitation takes place at Cherapunji (450" or more). The continuous region between the lower Gangetic plain and the east of central India up to the Bay of Bengal has an annual precipitation of not less than 50 inches. The region extending from north-west to south, which is also a continuous zone, receives 26 to 50 inches of precipitation annually. In the west the rainfall gradually decreases, ultimately resulting in desert and arid conditions in western Rajàsthan which has less than 10 inches rainfall. The precipitation increases gradually in the extreme east where the rainfall is not less than 75 inches annually, thus forming a humid region in the east. The country may conveniently be divided into the following seven rainfall zones (Table 14).

Temperature. In India, temperature normally decreases from north to south during the winter season (November to February) due to continental winds. The coldest months are December and January, the mean maximum varying from about 85° F. in some parts of the Peninsula to about 65° F. in the north-west, and the mean minimum ranging from about 75° F. in the extreme south to below 40° F. in the north-west. Sometimes cold waves

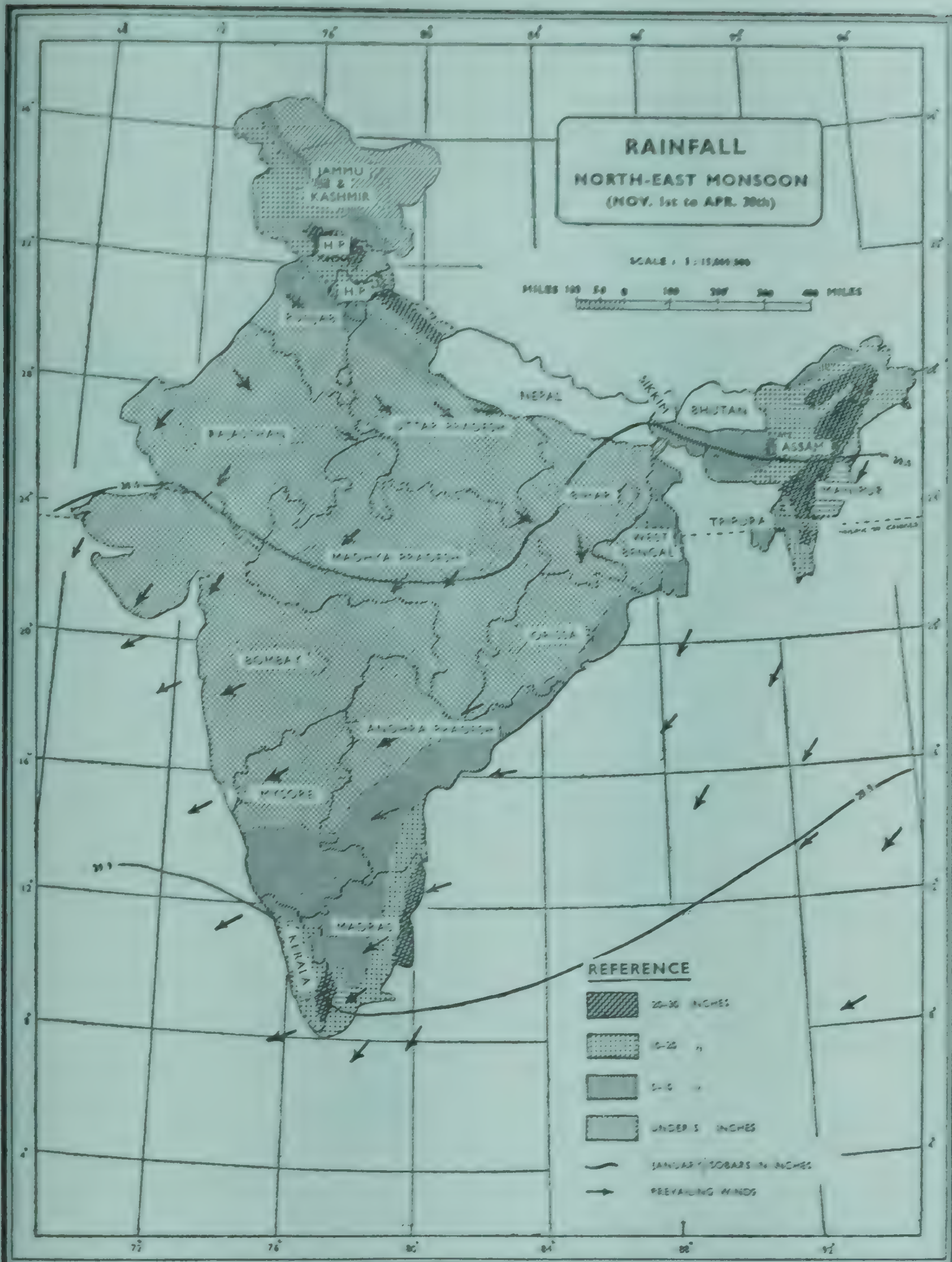


Fig. 5. Distribution of Rainfall from North-east Monsoon

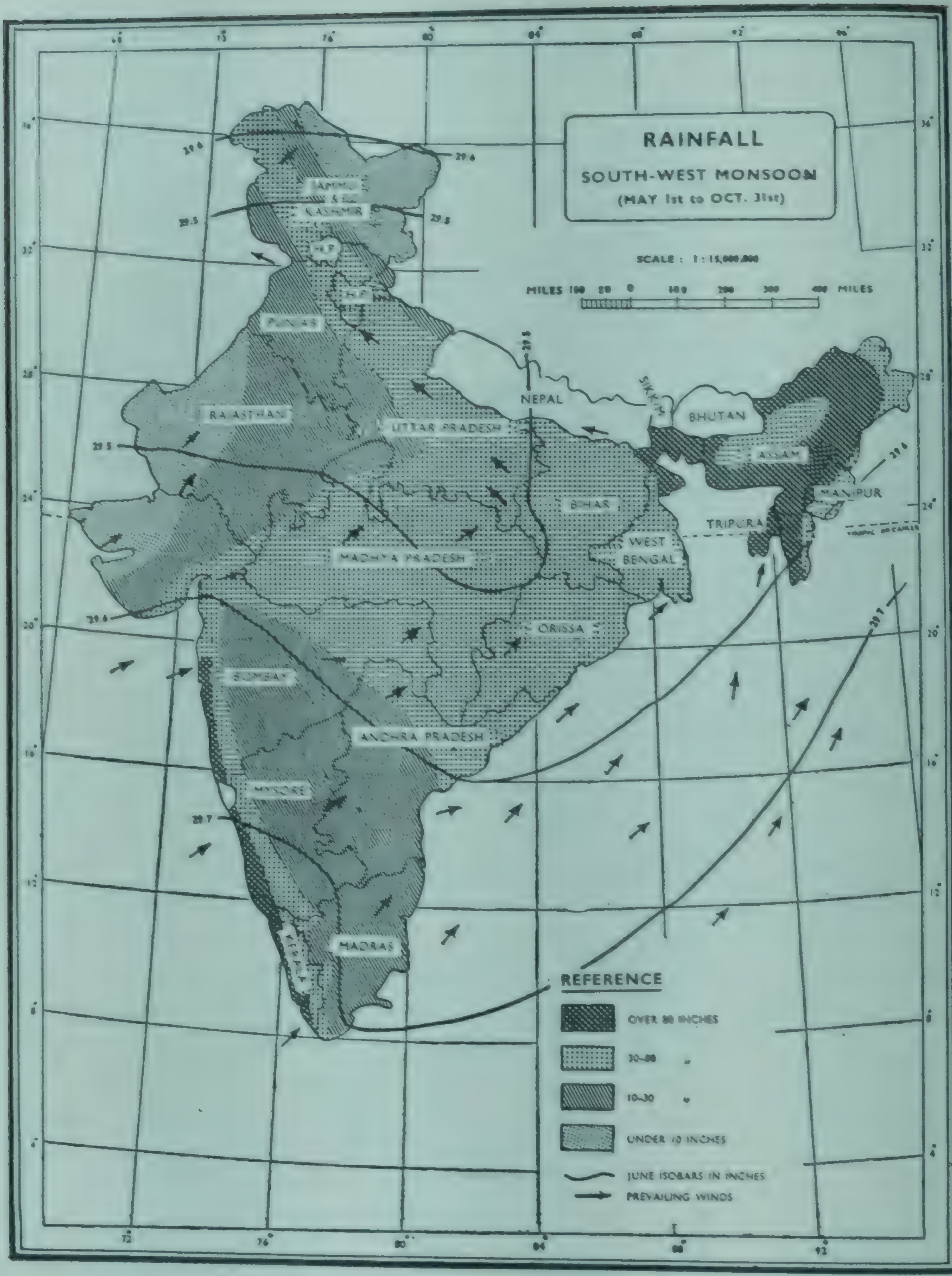


Fig. 6. _ Rainfall received from South-west Monsoon in different parts of India

TABLE 13. ANNUAL RAINFALL, MEAN MAXIMUM AND MINIMUM TEMPERATURES, AVERAGE DAILY WIND VELOCITY AND NUMBER OF CLOUDY DAYS PER MONTH OF A FEW REPRESENTATIVE LOCALITIES OF INDIA (AVERAGE OF THE YEAR 1952 EXCEPT RAINFALL WHICH IS THE NORMAL ANNUAL RAINFALL)*

Locality	Normal annual rainfall (inches)	Temperature						Average daily wind velocity			Number of cloudy days per month		
		Annual	Mean	Mean	Dec.-May	Mean	June-Nov.	Annual	Mean	Mean	Mean	Mean	Mean
		Max. ° F.	Min. ° F.	Max. ° F.	Min. ° F.	Max. ° F.	Min. ° F.	Miles per hour	Dec.-May Miles per hour	June-Nov. Miles per hour	Annual	Dec.-May	June-Nov.
Ferozepur	23·26	89·7	61·4	83·9	56·1	95·5	68·8	1·0	0·87	1·13	3·2	2·3	4·0
Ludhiana	28·89	90·8	63·3	85·9	56·3	95·7	70·4	1·0	0·55	1·4	4·3	2·8	5·7
Kanpur	34·96	91·0	67·8	89·5	62·6	92·5	73·1	5·1	4·9	5·2	6·0	3·7	8·2
Patna	46·70	89·4	69·1	88·2	62·2	90·5	75·9	4·4	4·1	4·1	6·3	2·1	10·5
Shillong	79·66	69·9	53·7	67·2	43·6	72·2	62·3	1·7	2·4	1·1	16·5	10·3	22·7
Ajmer	21·21	89·0	65·9	87·3	60·1	90·7	70·0	4·9	4·31	5·5	3·8	1·6	6·0
Bhopal	52·46	90·3	65·9	92·0	63·1	88·5	68·9	7·9	7·4	8·6	6·0	1·3	10·5
Nagpur	49·29	93·7	68·7	95·6	66·1	91·7	71·3	4·9	4·5	5·4	7·5	1·5	13·5
Akola	33·28	94·9	69·1	94·3	67·3	95·6	70·5	5·4	4·0	5·2	5·0	0·85	9·2
Cuttack	58·02	90·3	72·6	92·3	69·3	88·2	76·2	2·9	2·7	3·2	9·5	3·2	16·0
Rajkot	25·51	93·5	67·1	94·3	62·9	92·7	71·3	10·4	9·0	11·8	3·3	0·16	6·5
Ahmedabad ..	29·43	94·9	68·9	95·9	65·8	93·8	72·3	4·5	4·5	4·4	3·4	0·0	6·8
Surat	55·15	92·8	71·3	95·8	68·3	91·5	74·5	5·3	4·5	6·15	5·3	0·0	10·51
Nanded	37·20	—	—	—	—	—	—	—	—	—	—	—	—
Dharwar	27·63	—	—	—	—	—	—	—	—	—	—	—	—
Bellary	22·15	91·4	72·4	93·4	71·7	89·2	73·2	5·6	3·8	7·3	3·7	3·16	4·16
Coimbatore ..	26·02	88·1	71·8	90·7	71·6	85·4	71·9	7·7	6·1	7·2	3·5	4·0	5·0
Ramanathpuram ..	30·67	—	—	—	—	—	—	—	—	—	—	—	—

* Data compiled from the monthly weather reports of the Indian Meteorological Department, Poona, 1952.

TABLE 14. RAINFALL ZONES OF INDIA

Annual rainfall (inches)	Region
Under 10	Western Rajasthan, northern Jammu and Kashmir.
10-20	Central Rajasthan, South-west Punjab, Kutch (Bombay State), central Jammu and Kashmir.
21-40	Central and southern Jammu and Kashmir, eastern Punjab, Delhi, Uttar Pradesh, western Madhya Pradesh, eastern Rajasthan, parts of Bombay State (Saurashtra, central and eastern parts), central and eastern Mysore State, Madras State and Andhra Pradesh.
41-60	Himachal Pradesh, central Jammu and Kashmir, North-eastern Uttar Pradesh, Bihar, Bengal, eastern Madhya Pradesh, Orissa, eastern Andhra Pradesh and eastern Madras State.
61-80	Some parts of South-east and North Bengal, eastern and northern Orissa, North-eastern Bihar, northern Uttar Pradesh, parts of Himachal Pradesh and northern and central Assam.
81-100	Some parts of western coast of Bombay, Mysore and Kerala States and Assam.
Over 100	Tripura, Assam hills, and some parts of western coast of Bombay, Mysore and Kerala States.

from the Caspian and Turkistan regions move into North India and northern Peninsula when temperatures drop down to about 15° to 20° F. below the normal, followed by several degrees of frost in the plains of northern India.

In March, the mean maximum temperature generally exceeds 95° F. in the south of the Vindhyas, and is over 100° F. in parts of the Deccan. In April, the mean maximum temperature is above 100° F. in the South-west Punjab, Madhya Pradesh, Orissa and Andhra Pradesh. The mean maximum temperature in May is over 105° F. in most parts of the North-west and central India. Sometimes, during May, a maximum temperature as high as 120° F. is recorded in West Rajputana and the South-west Punjab. The mean minimum temperature rises above 70° F. in almost all parts of India in May, and it exceeds 80° F. in the eastern half of the Peninsula. In general, North India is hottest with dry air and cloudless skies, while South India is far cooler. The West Coasts of the Peninsula have a mean temperature of 82° to 85° F. in April and May. It does not exceed 100° F. The nights in the south are, however, warmer than those in the north, and the diurnal range is less than 15° F.

The maximum temperature falls rapidly after the break of the south-west monsoon in central India. In June, the maximum temperature in North-west India is over 105° F., as in May, while in July it remains below 100° F. In August, there is a further fall in temperature, and at the time of the retreat of the monsoon in the middle of September, the maximum shows a little upward trend. The mean maximum temperature during October is below 100° F. in North-west India, and in November temperatures are far below 100°F. In the Punjab the mean minimum temperature is below 50° F. in

November, and on some days it falls below the freezing point in the extreme north. Normally the mean maximum temperature increases from the south-east to north-west in May, while the mean minimum temperature in January increases from the north towards the south.

There is also a regular diurnal change in temperature. On an annual average, the diurnal range is about 25° to 30° F. in North-west India. It decreases towards the east and south. In the north-east and on the West Coast the range is 15° to 20° F. In the north-west of the Peninsula the range is between 30° and 35° F. during February and March.

Wind Velocity and Cloudiness. The wind velocity, in general, is about two to three miles an hour in most parts of North India, while in South India it is a little more, being about five miles and going up to even seven to nine miles in the West Coast area. In the eastern part, in East Orissa and South Bengal near the Bay of Bengal, the wind velocity averages about five to nine miles an hour. During the monsoon season, however, the velocity generally increases during June to September (Table 13—Page 47).

The wind velocity is the least at the time of sunrise, and greatest from 1 to 2 P.M. The change in velocity is greater on clear than on cloudy days. It is most pronounced during summer and least in winter. In the northern plains, the velocity is maximum during the day and minimum during the night, while on the Himalayan mountains the position is just the reverse.

In general, there is a gradual gradation in the mean annual cloud amount from north to south except in the extreme north and north-east of the country. The months of January and February have clear days with only about 2 tenth cloud while during monsoon (June to September) the sky is usually cloudy in most parts of the country except in eastern Madras where skies are more cloudy during October-November. It has been observed that in January 2 to 4 tenths of sky cover show all clouds while low clouds in the same month are insignificant (0 to 2 tenths sky cover) in almost all parts of India (Chatterjee, 1954). In July, however, the case is reverse, and all clouds are more important covering 4-6 to 8-10 tenths of sky while low clouds (0-2 to 4-6 tenths of sky cover) are of less importance.

SOIL REQUIREMENTS

Cotton needs a soil with good moisture holding capacity. The soil should also have good drainage and aeration, as the crop cannot stand excessive moisture and water-logging. Under moderate rainfall conditions, cotton is grown on retentive clayey loams. With irrigation facilities, it is usually cultivated on sandy loam to loam soils.

As regards chemical properties of soils, the cotton plant can grow normally on soils with pH values ranging from 5·5 to 8·5. The humus content of the soils may be anything from less than one per cent. to more than five per cent. according to climatic conditions and cropping. However, soils well

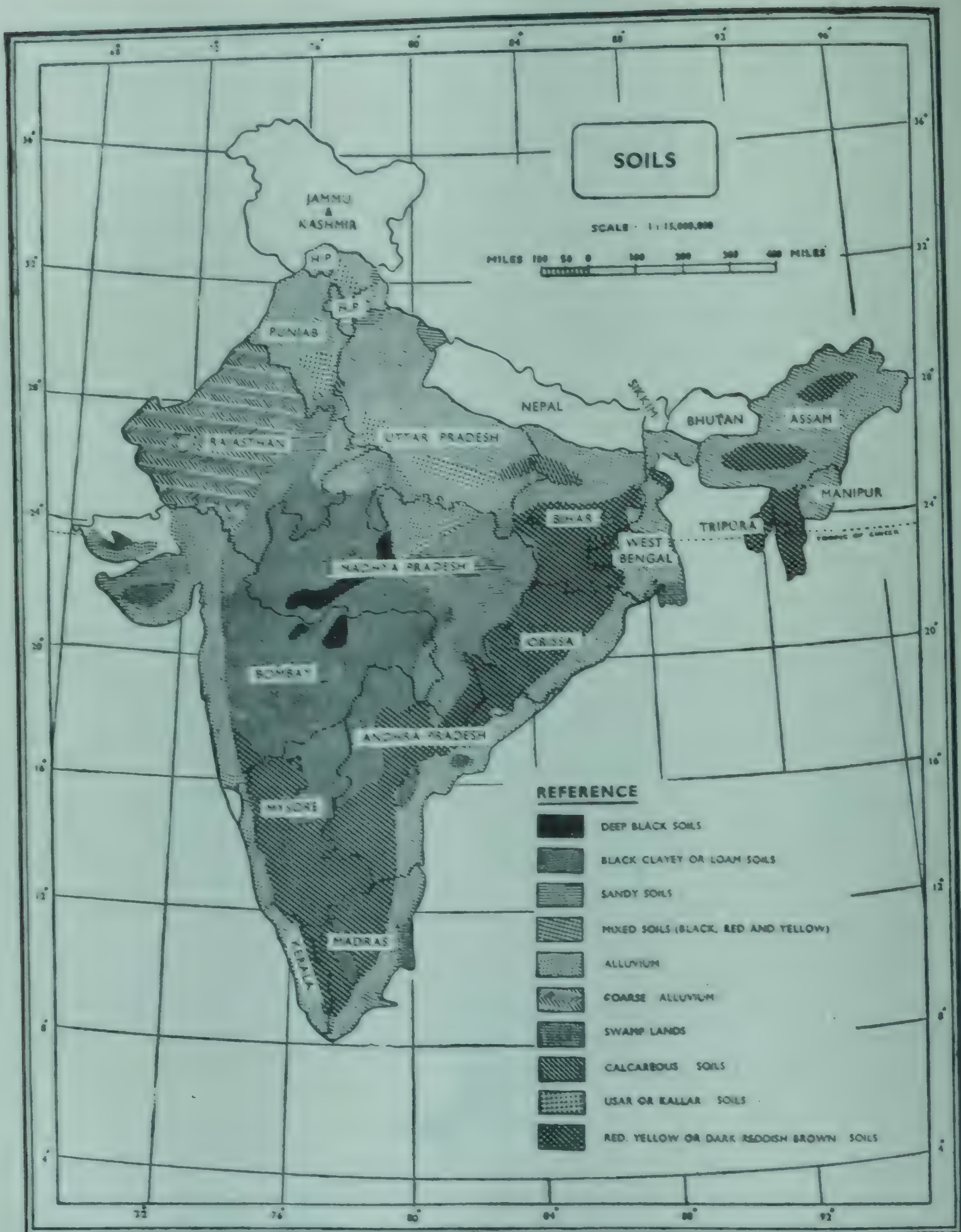


Fig. 7. Major Soil Types of India

supplied with organic matter or humus are the most productive. In plant nutrient status, the soils should be adequately rich, or else the shortfall has to be made good through fertilizers and manures. The lighter types of soils, on which cotton is grown under artificial irrigation, need liberal application of balanced fertilizers for the most profitable cultivation of the crop. On the other hand, very heavy clayey soils, if used for cotton growing, need not only fertilizers but also adequate organic matter to maintain optimum drainage and aeration conditions.

The major groups into which Indian soils may be classified are : (*i*) alluvial soils including deltaic alluvium, coastal alluvium and inland alluvium ; (*ii*) black soils of varying origin, including the typical black cotton soils or *regur* of the Deccan plateau; (*iii*) red soils, including red loams, yellow earths, etc. ; (*iv*) laterites and lateritic soils ; (*v*) mountain and hill soils ; (*vi*) arid and desert soils ; (*vii*) saline and alkali soils ; and (*viii*) peaty and other organic soils. The distribution of these groups in the country is shown in Figure 7.

The cotton crop is grown in India mainly on the following major soil groups :

1. Alluvial soils.
2. Black cotton soils.
3. Red sandy loams to loams.
4. Lateritic soils.

Of these, black cotton soil is the predominant type employed for the rainfed crop in Peninsular and southern India, and alluvial soils for the rainfed as well as irrigated crops in northern India. Reddish brown and lateritic soils are used mostly for the irrigated crop in the low rainfall tracts of Madras and Mysore. A limited area of hill soils in Assam is also used for growing cotton.

Alluvial Soils. These are also called the Indo-Gangetic alluvium as the largest portion of this group occurs in that region. These soils are found in the greater part of Rajasthan, the Punjab, Uttar Pradesh, Bihar, Bengal and parts of Assam and Orissa. They are also found in the valleys of Brahamaputra and Surma in Assam, Narbada and Tapti in Madhya Pradesh and Bombay, and Godavari and Krishna in the south. The river deltas on the coast form the deltaic alluvium. The sub-montane belt along the Himalayan range in Uttar Pradesh, Bihar and Bengal is also included in this group. The sandy soils of Ahmedabad and loam soils of Kaira in Bombay too are of alluvial origin. The group is rather ill-defined. The soils differ greatly in texture and consistency, ranging from sand through loams and silts, to heavy clays that are ill-drained and sometimes charged with injurious accumulations of sodium salts producing a sterile, deflocculated condition called *usar*. They also differ greatly in depth, exceeding 3,000

feet in some places. The colour of these soils is generally gray, light brown or yellowish, but those occurring in the valley of Narbada, Tapti, Godavari and Krishna in Peninsular India are of black colour, having been formed by the deposition of the decayed organic matter and materials resulting from the weathering of 'trapean' or volcanic rocks. There is no marked differentiation into various horizons and the profile is often devoid of stratification. The alluvial soils are generally deficient in nitrogen and humus, and occasionally in phosphorous. Potash is usually adequate, ranging between 0·65 to 0·70 per cent. in the Indo-Gangetic soils and 0·25 to 0·35 per cent. in the Brahamaputra basin. The lime content shows a great variation even in adjoining localities. A common feature is the possession of *kankar* or lime nodules which may occur inter-mixed with soils or as an impervious, hard substratrum at varying depths. Ease of cultivation and good response to irrigation and manuring are the other important features of the Indo-Gangetic soils. In West Rajasthan and in the districts of Ferozepur and Sangrur in the South Punjab, the alluvium in many places is covered with shifting sand dunes. These soils are normally unproductive, but fairly good crops can be grown on them under artificial irrigation. In the western and central Punjab, loams and sandy loams with occasional patches of clay soils form the predominant type, whereas in the eastern districts, soils vary from fertile loams to heavy clays.

The soils in Uttar Pradesh tend to become heavier from north-west to south-east. In the districts of Agra, Mathura, Aligarh, Meerut and Delhi, where the conditions are semi-arid, patches of alkali soils as well as alluvium covered by wind borne sands are quite common. In eastern Uttar Pradesh and the adjoining State of Bihar, where the rainfall is relatively heavy, considerable areas are somewhat low lying and subject to damage by floods. However, the freshly deposited silt enhances soil fertility. In the high lying parts, the soil consists of old alluvium.

In Bengal, where the rainfall is still heavier and the rivers generally slow running, the soils along the river banks contain an abundance of fine silt and those away from the rivers are rich in clay. The deltaic areas near Calcutta are low lying and swampy.

In Assam, the soils in the valley of Brahamaputra consist largely of sand and sandy loam, whereas those in the basin of the sluggish Surma river consist largely of silt and clay.

Depending on rainfall and other climatic factors, the alluvial soils are suitable for cotton cultivation. Where irrigation facilities are available and proper manuring is practised, the crop outturns are as high as anywhere else in the world.

Black Cotton Soils. The group derives its name from the black colour of its soils and their eminent suitability to the growing of cotton. It is locally called *regur* in some tracts. This group covers central and western Madhya

Pradesh, almost the whole of Bombay State, southern districts of Orissa, South and Coastal Andhra Pradesh and the northern districts of Mysore. Black soils also occur in Bundi and Tonk districts of Rajasthan in the north, Bundelkhand Division of Uttar Pradesh in the east, and some of the central and southern districts of Madras in the south. In many tracts, particularly in the eastern and southern parts of the country, black soil often occurs in close proximity to red soil. In the vicinity of hills, red soils merge imperceptibly into black soils. The soil close to the hills is red and with the increase of distance from the hills, the black soil in increasing thickness occurs.

Depending on the mode of genesis, several physiographical sub-divisions are recognisable within this group. The upland soils of Vindhya and Satpura range are residual and mainly sandy and gravelly. The plateaus of Malwa and the Deccan also have residual soils, formed *in situ* by the weathering of 'trap' material, consisting of disintegrated basaltic rocks. They are found as a black layer of medium thickness lying over disintegrated *murum* and are usually well drained loams of medium fertility. The soils in the valley of Narbada, Tapti, Godavari and Krishna are of alluvial origin, the soil material having been brought down by the rivers from the higher black soil areas. These soils are very deep and fertile loams or clay loams. The level soils of central and southern Vidarbha (Berar) are partly residual and partly alluvial in origin and are very deep and exceedingly fertile loams or clay loams with a thick substratum of yellow clay and lime. At the foot of the hills, however, the soils are lighter black in colour, coarser in texture, often eroded and shallow, and generally poor in fertility. The black soils of central and southern Gujerat and southern Saurashtra in Bombay are very deep and probably formed by marine and river action.

Due to differences of local topography, rainfall and mode of genesis, the black soils show considerable variation in morphology as well as chemical composition.

It would be observed that the black cotton soils are usually deficient in nitrogen, phosphoric acid and organic matter but rich in potash, iron, lime, alumina and calcium and magnesium carbonate. They are highly clayey and extremely soft when wet, but on drying, break up into hard baked blocks and develop cracks which may be two to four inches wide and one to four feet deep. The filling of cracks with loose surface soil by wind and water action causes mixing of lower and upper layers. Because of this action and the effect of cracking, the black soil is said to plough itself. Medium deep soils overlying disintegrated *murum* are well drained. However, all black soils are highly water retentive and even in the hot weather they are wet and sticky at a depth of 18 to 24 inches. The soils of this group are fairly fertile and give reasonably good yields despite continued cultivation without proper manuring. The black soils are generally considered unsuitable for heavy irrigation. However, under judicious irrigation and manuring, they can

produce good yields of cotton. These soils are very well suited to the cultivation of rainfed cotton and a host of other crops.

Red Soils. These cover large parts of Madras, Mysore, North-east Andhra Pradesh (Telengana) and the tract running along eastern part of Madhya Pradesh to Chhota Nagpur and Orissa. They are also commonly met in the Santhal Parganas of Bihar ; Birbhum, Bankura and Midnapur districts of Bengal ; the Khasi, Jainti, Garo and Naga hills of Assam ; Jhansi, Banda and Hamirpur districts of Uttar Pradesh ; and the territory east of Aravalli hills in Rajasthan. The red soils are generally characterised by : (*i*) a light, porous, friable structure; (*ii*) absence of lime *kankar* and free carbonates ; (*iii*) presence of soluble salts in quantities not exceeding 0·05 per cent.; (*iv*) neutral to acid reaction; and (*v*) deficiency of nitrogen, humus, phosphoric acid and lime. They differ greatly in depth and fertility, and can grow many types of crops under rainfed as well as irrigated conditions.

Laterites and Lateritic Soils. The soils of this group developed on the summits of hills of the Deccan, Madhya Pradesh, Rajmahal hills, Eastern Ghats and certain parts of Orissa, Assam, Mysore and Malabar. On higher levels, these soils are exceedingly thin and gravelly, but on lower levels and in valleys, they are fairly deep and range from heavy loams to clays. Usually the lateritic soils are poor in nitrogen, phosphoric acid, potash, lime and magnesia. While they are generally low in fertility, they respond readily to manuring and good cultivation. Under favourable conditions, they can produce a good crop of cotton.

Table 15 shows mechanical and chemical analyses of: (*i*) alluvial soils; (*ii*) black soils; (*iii*) red soils; and (*iv*) laterite soils.

Cotton Soils in Different States. As mentioned already, cotton is grown in India on a variety of soils. In the Punjab and Uttar Pradesh, the crop is grown generally on light to heavy alluvial loams, sandy and fairly uniform in character. In North-west Rajasthan cotton is grown under irrigation on light alluvial loams, as in the adjoining parts of the Punjab. In south-eastern parts of the State, the crop is cultivated under rainfed conditions on well drained, water retentive black soils of medium depth. In Bihar, the crop is grown on high lying old alluvium. In Assam, the crop is cultivated on the hill slopes in Naga and other tribal areas, where though the rainfall is very heavy, the water flows away quickly into the valleys and thus the crop does not suffer from water-logging. In Madhya Pradesh, the crop is grown almost wholly on residual black soils of varying depth. On the Malwa plateau, the soils are medium to shallow, whereas in Nimar and Bhopal tracts, they are somewhat deeper and heavier. In the valley of Narbada, cotton soils are deep, fertile and alluvial in origin. In Gwalior tract, the crop is cultivated partly on alluvial and partly on black soils.

In Bombay, the cotton growing tracts may be divided into five main divi-

sions. In Saurashtra, the cotton is grown on alluvial soils in the north and black soils of marine origin in the south. In North Gujerat, the crop is cultivated on alluvial loams (*goradu*), varying from drift soils of Ahmedabad to immensely deep and rich loams of Kaira. In middle and south Gujerat, the crop is grown on black alluvial soils deposited by Tapti, and Narbada, and corresponding in composition to the black soils of Vidarbha. In Khandesh and Marathwada, the cotton soils are of the true *regur* types, having been formed by weathering of 'trap' rock. However, the soils vary in texture from sand to clay loams and in depth from 5 to 20 feet. In Vidarbha, the cotton soil is almost wholly of the black cotton variety. It is an exceedingly fertile loam, often of great depth. In Nagpur tract, the soil is somewhat shallower and lighter. The soils of Vidarbha are partly residual and partly alluvial in origin.

In Mysore, the crop of Raichur and Dharwar Divisions and of Chitaldrug and Bellary districts is grown on typical *regur* soil, residual in origin and varying in depth. The soils of the western and northern parts of this tract are rather shallow and inter-mixed with fairly large areas of red soils. In central and southern Mysore, cotton is cultivated rainfed or irrigated on red granitic and lateritic soils.

In North Andhra Pradesh, i.e., Telengana, cotton is grown in the districts of Adilabad and Khammam, in both of which large tracts of black cotton (*regur*) soil of 'trappean' origin are met with. The soils of Khammam district are deeper than those of Adilabad. In other districts of Telengana cotton is grown on a very small scale on deeper types of red soils. In Rayalaseema, cotton is cultivated on both black and red soils, whereas in some parts of Coastal Andhra Pradesh, heavy black, paddy lands are occasionally used for growing cotton as a second crop after paddy.

In Madras, the southern and central districts of Tirunelveli, Ramanathpuram, Coimbatore, Mathurai and Tiruchirapally grow cotton on black soils under rainfed conditions. However, in some parts of this tract the American Cambodia variety is grown on red soils, as a rainfed or irrigated cold weather crop and a wholly irrigated summer (March to September) crop. The black soil in some places is saline. In some parts of Coimbatore and Salem districts, perennial varieties of cotton are grown on poor and gravelly soils.

TABLE 15. MECHANICAL AND CHEMICAL

State of Locality	Annual rainfall (inches)	Parent rock	Depth of horizon (inches)	pH	Organic matter (%)	Mechanical Composition (%)			
						Coarse sand	Fine sand	Silt	Clay
				1. ALLUVIAL SOILS					
A. Rajasthan									
Sri Ganganagar	20	Sand Stone	0-10	8·20	0·408	1·30	29·3	35·5	15·91
B. Punjab									
Jullundur ..	35		0-12			33·4	36·5	19·8	6·7
C. Delhi									
Gheora-Tekri ..	26		0-6				76·0	10·9	13·0
D. Uttar Pradesh									
Kanpur ..	36		0-8	7·2		0·2	61·8	1·5	36·4
E. Bihar									
Sabour ..	45		0-6						
F. Bengal									
Burdwan ..	58		0-6			70·2		12·22	13·13
G. Bombay									
Gujerat ..	40	Indo-Gangetic Alluvian	Surface soil	7·0-8·0					10·20
				2. BLACK SOILS					
A. Rajasthan									
Kotah ..	33	Sand Stone	0-13	8·50	1·54	1·23	38·17	21·46	38·16
B. Uttar Pradesh									
Hamirpur ..	35		0-17	6·8		1·7	39·5	20·5	34·0
C. Madhya Pradesh									
(*i*) Indore ..	45								
(*ii*) Jabalpur ..	60			7·85		1·95	8·12	32·04	45·54
D. Bombay									
(*i*) Akola ..	35			8·2		2·62	8·53	34·93	36·92
(*ii*) Surat ..	60		0-6				66·5		
(*iii*) East Khandesh	40			8·52			62·32		
(*iv*) Nanded ..	33	Basalt	0-12	7·30	0·828	4·25	8·69	11·27	61·32
E. Andhra Pradesh									
(*i*) Kurnool ..	25		0-12	8·91		8·2	14·9	23·3	45·7
(*ii*) Cuddapah ..	30					9·87	13·12	11·35	20·07
F. Mysore									
(*i*) Dharwar ..	30	Granite	0-6				65·33		
(*ii*) Raichur ..	22	Granite	0-6	8·80		18·90	13·50	16·05	47·40
(*iii*) Chitaldrug ..	30		0-12	8·0		8·0	20·59	7·9	58·6
G. Madras									
Coimbatore ..	40		0-6			35·5	21·5	5·7	33·6

ANALYSES OF SOILS OF INDIA

Chemical Composition (%)												Total exchange-able bases mg. equi-valent/100g.
Mois-ture	Loss on igni-tion	S_1O_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	N	Car-bon/ Nitro-gen ratio	
3·32	6·58	88·57	5·76	1·55	0·39	0·21	0·82	0·08		—	—	—
							0·786	0·211		0·046		
					0·48		0·46	0·03		0·034		
	1·1	4·0	2·8		0·5	0·5	0·47	0·1		0·05		9·6
					0·26	0·19	0·36	0·066		0·047		
	2·13	6·09	5·58		0·28	0·66	0·56	0·04		0·042		
							0·204	0·1–0·23		0·03–0·07	6–13	25–30
3·12	4·8	79·35	8·89	4·48	0·48	0·53	0·67	—	0·18	0·06	13·9	32·2
	5·25		5·86	5·52	0·98	1·15	0·37		0·08	0·056		
							0·857		0·07	0·046		
			9·74	8·81	6·07	2·77	0·61		0·05			50·0
6·77			8·97	9·41	4·85	0·43	0·39	0·51	0·09	0·008		
8·17					2·23	0·1	0·25	0·1	0·093			
									0·053	0·030	15·94	58·62
	5·52				2·54		0·55		0·048	0·025		50·0
	5·9		18·55		1·84	0·48	0·66		0·03	0·03		39·6
7·74	6·87				0·37	0·39		0·002		1·82		62.0
		63·98	17·19		6·05	3·22	0·68	0·90	0·020	0·019		51·10
4·99	5·04		9·9						0·03	0·06		
3·6	4·24		7·06	3·06	3·67	1·49	0·39	0·18	0·05	0·034		26·9

TABLE 15. MECHANICAL AND CHEMICAL

State of Locality	Annual rainfall (inches)	Parent rock	Depth of horizon (inches)	pH	Organic matter (%)	Mechanical Composition (%) Coarse sand	Fine sand	Silt	Clay
			3. RED SOILS						
A. Bihar									
Ranchi ..	60		0-6			33·3	24·7	13·9	25·8
B. Orissa									
Sambalpur ..	65		Sub-soil			51·8	20·0	21·6	6·1
C. Bengal									
Bankura ..	60		0-6			45·52	19·13	16·4	17·0
D. Madhya Pradesh									
Raipur ..	50					43·38	14·17	24·33	18·12
E. Andhra Pradesh									
Raichur dist. ..	22	Granite	0-6	7·29		51·50	25·42	7·90	17·93
F. Mysore									
(i) Dharwar ..	28	Granite	Surface soil	7-7·5					20·40
(ii) Bangalore ..	35					19·1	61·5	4·3	10·5
G. Madras									
Salem ..	40								
H. Assam									
Govt. Upper Shillong Farm K. & J. hills ..	100		0-10½	4·6		17·6	25·5	34·0	16·0
I. Assam									
Cotton Research Station, Tura, Garo hills ..	130		0-2	4·4		22·2	30·0	26·0	16·0
			. LATERITE SOILS						
A. Assam									
Khasi hills ..									
B. Orissa									
C. Madhya Pradesh									
D. Mysore									
Bidar ..	30	Laterite from Basalt	Surface soil			21·84	10·71	14·50	47·56
E. Malabar									
Pattambi									

Analyses of Soils of India—(*Contd.*)

Chemical Composition (%)												Total ex-change-able bases mg. equi-valent/ 100g.
Mois-ture	Loss on igni-tion	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	N	Car-bon/ Nitro-gen ratio	
	4·5	84·2	3·4	6·1	0·22	0·46	0·61	0·16	0·02	0·075		
3·0	5·3		11·8	5·0	1·02	0·74	0·73	1·29	0·03			
1·6	2·62	85·6		9·96	0·17	0·43	0·86		0·043	0·028		
1·76												
		78·35	9·66	3·90	1·29	1·00	2·57	1·52	0·049			16·20
												25·30
1·08	2·12	93·2	4·35		0·18	traces			0·045	0·035		
	2·62	57·03	3·08	3·35	0·14	0·26	0·23	0·51	0·05	0·042		
4·4	12·8	—	—	—	—	—	0·008	—	0·013	0·239	14·35	—
1·8	7·2	—	—	—	—	—	0·018	—	0·004	0·186	—	—
—	—	—		38·50	22·41	16·25	—	—	—	—	—	—
					Depth of horizon 0·6″							

CHAPTER III

TAXONOMY

The genus *Gossypium*, to which the cotton plant belongs, is a member of the natural order *Malvales*, family *Malvaceae*, series *Hibisceae* of the dicotyledonous group of plants. It obviously possesses the various morphological characters specific to each taxonomic unit of which it is a member.

The genera of *Hibisceae* are distinguished from each other on the basis of the following factors : (*i*) type of inflorescence ; (*ii*) number, size and persistence of the bracteoles ; (*iii*) form of the calyx ; (*iv*) nature of the style — clavate or branched ; (*v*) distribution of the oil glands ; (*vi*) character of the fruit ; (*vii*) nature of the seed ; and (*viii*) chromosome numbers.

The genus has been described by Hutchinson (1947) as follows :

Haploid chromosome number 13 or 26. Annual *sub-shrubs*, perennial shrubs or small trees. *Branches* terete or slightly angled, tomentose, hairy or glabrous, of two kinds, i.e., monopodial vegetative branches and sympodial fruiting branches, the latter sometimes reduced to jointed peduncles or flowering spures. The whole plant irregularly dotted with black oil glands. *Bracteoles* 3, usually foliar and persistent, sometimes small, or minute, rarely caducous. *Calyx* cup-shaped, truncate, undulate or 5-pointed. *Stamens* ∞ the lower parts of the filaments united into a tube, the upper free, bearing unilocular *anthers*. *Styles* clavate or furrowed, rarely divided at the tip. *Ovary* 3-5 locular, ripening to a dry, brittle, loculicidally dehiscent capsule. *Loculi* with seeds indefinite (rarely two only). Seeds covered with one or two coats of long unicellular hairs, or in some wild species almost naked.

CLASSIFICATION OF THE GENUS INTO SPECIES

Taxonomists from Linnaeus onwards have divided the genus into a number of species. The actual number proposed by each investigator naturally depended on the then existing concept of species, which in turn was based on the knowledge of the heritable variation and the plant material available at the time.

Modern classification of the genus into 20 species by Hutchinson (1947) is based on the concept of the genetic nature of species differences, which is similar to that of Clausen, Keck and Hiesey (1939). Hutchinson's grouping into sections, species and varieties corresponds to cœnospecies, ecospecies and ecotypes, respectively, of Clausen *et al.* (1939).

Before discussing the details of this recent taxonomic work on *Gossypium*, it would be useful to give a short review of the work done earlier.

Early Workers. Linnaeus distinguished five to six species in *Gossypium* on the basis of the material from the cultivated types that he studied. DeCandolle (quoted from Hector, 1936), accepted 13 species within the genus,

while Parlatore recognised only seven species. Todaro considered that there were 54 species within the genus. Watt (1907) divided the wild and cultivated cottons into five sections on the basis of presence or otherwise of fuzz and lint on seed, nature of bracteoles and other plant characters. Each section was further sub-divided into a number of species, the total being 29 with 16 varieties.

With regard to the genus as cultivated in India, Gammie (1907) recognised six groups amongst the indigenous cultivated types besides the New World imported group of Dharwar-American cotton. Amongst the Asiatic groups, eight species comprising 12 varieties and sub-varieties were recognised. On the other hand, only one species, *G. hirsutum* was mentioned in the New World group.

Leake and Ram Prasad (1914) attempted the classification of the cotton material that they were handling for genetic studies and stressed the importance of monopodial and sympodial plant habits in the classification of cotton.

Recent Workers. The classification proposed by the early workers was broadly based on purely morphological characters. Subsequently, with the advance of the knowledge regarding the basis of variation and evolution, the concept of species was broadened and simplified, so that only those groups which differed in genetical architecture or between which cytological barriers existed, were regarded as separate species. As such, it became clear that the scientific classification must be based on morphological, physiological, genetical, ecological, cytological and serological knowledge of the genus.

Efforts in this direction were made by Zaitzev (1928), Mauer (1928) and Harland (1932). All these workers divided the genus *Gossypium* primarily into two groups, one with 13 haploid chromosomes, and the other with 26 as the basic number. Zaitzev (1928) and Mauer (1928) further sub-divided these groups into two each on the basis of geographical distribution.

Zaitzev (1928) was of the opinion that wild cottons should be removed from the genus *Gossypium* and he recognised 16 species within the genus.

Mauer (1928) came to the conclusion that Zaitzev's four sub-groups were in essence four well differentiated species.

Harland (1932) disagreed with Zaitzev (1928) regarding the transfer of the wild cottons from the genus *Gossypium*. He proposed the division of the genus into 16 species, of which five were cultivated.

Hutchinson and Ghose (1937) accepted the classification of the genus into 16 species suggested by Harland.

MODERN SYSTEM OF CLASSIFICATION

On the basis of a detailed study of chromosome behaviour, geographical distribution, morphological characters and crossing behaviour of different species, Hutchinson (1947, 1954) suggested that the genus be divided into the following 20 species, grouped under eight sections corresponding to coeno-

species of Clausen. Subsequently Dauwes (1953) suggested the separation of *G. areysianum* from section Anomola to section Stocksiana. The group is now as under:

1. Capsules with hairs on sutures, seeds without lint ; n=13.

a. Australian distributon :
  b. *section Sturtiana*
    c. *G. sturtii* .. .. (1)
    cc. *G. robinsonii* .. .. (2)
aa. American distribution :
  b. *section Erioxyla*
    c. *G. aridum* .. .. (3)
    cc. *G. armorianum* .. .. (4)
    ccc. *G. harknessii* .. .. (5)
  bb. *section Klotzschiana*
    c. *G. klotzschianum* .. .. (6)
    cc. *G. raimondii* .. .. (7)
  bbb. *section Thurberana*
    c. *G. thurberi* .. .. (8)
    cc. *G. trilobum* .. .. (9)
    ccc. *G. gossypioides* .. .. (10)
aaa. African and Arabian distribution :
  b. *section Anomala*
    c. *G. triphyllum* .. .. (11)
    cc. *G. anomalum* .. .. (12)
aaaa. North Indian, Arabian and Somaliland distribution:
  b. *section Stocksiana*
    c. *G. stocksii* .. .. (13)
    cc. *G. areysianum* .. .. (14)
    ccc. *G. somalense* .. .. (15)

2. Capsules without hairs on sutures and seeds with lint.

a. Old World ; n=13
  b. *section Herbacea*
    c. *G. arboreum* .. .. (16)
    cc. *G. herbaceum* .. .. (17)
aa. New World ; n=26
  b. *section Hirsuta*
    c. *G. hirsutum* .. .. (18)
    cc. *G. barbadense* .. .. (19)
    ccc. *G. tomentosum* .. .. (20)

The related groups usually possess similar genetic potentialities and, therefore, show a considerable parallelism in variation. This makes the compilation of a dichotomous key impossible. Tables 16 (a) and (b) give important diagnostic characters by which different sections and species can be distinguished. Table 17 gives the distribution of and the types covered by the different wild species as described by Hutchinson, Silow and Stephens (1947).

The cultivated species of *Gossypium* belong to sections **Herbacea** and **Hirsuta,** and are *G. arboreum* L. *and G. herbaceum* L. belonging to the former and *G. hirsutum* L. and *G. barbadense*, to the latter. The Indian cotton crop belongs **to three** species, viz., *arboreum*, *herbaceum* and *hirsutum*.

TABLE 16 (a). KEY TO SECTIONS

(Hutchinson, Silow and Stephens, 1947)

Capsule and seed hairs	Stem and leaf covering	Fruiting branches	Leaf lobing	Bracteole shape and toothing	Androecium	Section
Capsules with hairs on sutures, seeds naked or fuzzy, but never linted	Glaucous	2-α jointed sympodia	Lobed or entire	Ovate entire	—	I. STURTIANA
	Glabrous or nearly so, glaucous	Jointed peduncles or flowering spurs	Entire or nearly so	Reduced, or ovate and caducous	—	II. ERIOXYLA
	Hairy	2-α jointed sympodia	Entire	Many toothed	—	III. KLOTZSCHIANA
	Glabrous or nearly so, not glaucous	α-jointed sympodia	Lobed	Entire or 3-toothed, sometimes reduced	—	IV. THURBERANA
	Hairy	Jointed peduncles or 2-α jointed sympodia	Lobed	Linear, usually 3-toothed	—	V. ANOMALA
	Hairy or nearly glabrous	2-α jointed sympodia	Usually Lobed Rarely with both leaves and bracteoles entire	Usually gashed or serrate	—	VI. STOCKSIANA
Capsules without hairs on the sutures, seeds linted	Variously hairy or nearly glabrous, not glaucous	α-jointed sympodia	Lobed	Entire, coarsely toothed or serrate, teeth rarely thrice as long as broad	Anther filaments short, all about the same length	VII. HERBACEA
					Anther filaments long, upper ones longer than the lower	*G. tomentosum* in VIII. HIRSUTA
				Coarsely toothed or serrate, teeth more than thrice as long as broad	—	VIII. HIRSUTA

TABLE 16 (b). KEY TO SPECIES

Section	Distinguishing features	Species	
STURTIANA	a. Leaves entire, broadly ovate	*sturtii*	(1)
	aa. Leaves deeply 3-lobed	*robinsonii*	(2)
ERIOXYLA	a. Leaves entire		
	b. Leaves acuminate, longer than broad	*aridum*	(3)
	bb. Leaves rounded or acute, as broad as long	*armourianum*	(4)
	aa. Leaves shallowly 3-lobed	*harknessii*	(5)
KLOTZSCHIANA	a. Bracteole teeth long acuminate		
	b. Bracteole teeth 10-15, capsule nearly twice as long as broad	*klotzschianum*	(6)
	bb. Bracteole teeth 6-10, capsule round	*klotzschianum* var. *davidsonii*	(7)
	aa. Bracteole teeth long linear, almost threadlike	*raimondii*	(8)
THURBERANA	a. Bracteoles scarcely cordate, triangular acute or acuminate		
	b. Bracteoles triangular acute, much shorter than the petals	*thurberi*	(9)
	bb. Bracteoles long acuminate, as long as the petal	*trilobum*	(10)
	aa. Bracteoles cordate, broadly ovate, acute, shorter than the petals	*gossypioides*	(11)
ANOMALA	a. Leaves divided to the base, lobes narrow	*triphyllum*	(12)
	aa. Leaves 1/3 to 4/5 palmatifid, lobes broad	*anomaleum*	(13)
STOCKSIANA	a. Bracteoles clawed at the base and divided along the upper margin into long radiating teeth	*stocksii*	(14)
	aa. Bracteoles somewhat cordate at the base, usually serrate along the upper margin rarely entire	*somalense*	(15)
	aaa. Bracteoles free, narrow, oblong-cuneate, generally 3-denate at the apex	*areysianum*	(16)

TABLE 16 (b). KEY TO SPECIES—(*Contd.*)

Section	Distinguishing features	Species	
HERBACEA	a. Bracteoles closely investing the flower, longer than broad, entire or with 3-4 coarse teeth near the apex. Capsules tapering	*arboreum*	(17)
	aa. Bracteoles flaring widely from the flower, usually broader than long, the upper margin usually serrated into 6-8 teeth. Capsules rounded, or with prominent shoulders	*herbaceum*	(18)
HIRSUTA	a. Staminal column short. Anthers loosely arranged, anther filaments longer above than below. Capsule surface smooth		
	b. Bracteole teeth triangular, less than thrice as long as broad	*tomentosum*	(19)
	bb. Bracteole teeth long acuminate, more than thrice as long as broad	*hirsutum*	(20)
	aa. Staminal column long. Anthers compactly arranged, on short filaments which are all about the same length		
	f. Capsules usually large (3·5 cm., or more long); capsule surface usually coarsely pitted, or rarely finely pitted, with black oil glands in the pits. Seeds bearing a copious and even coat of lint		
	(*i*) Capsules less than 6 cm., broadest near base, seed free	*barbadense*	(21)
	(*ii*) Capsules more than 6 cm. long, broadest near the middle and tapering at base, seeds connate	*barbadense* var. *brasiliense*	(22)
	ff. Capsules small (3 cm. long or less); capsule surface finely pitted with oil glands in the pits, almost smooth to the naked eye. Seeds bearing a scant irregular coat of lint	*barbadense* var. *darwinii*	(23)

TABLE 17. INCLUSION AND DISTRIBUTION OF DIFFERENT WILD SPECIES OF *Gossypium* AS DESCRIBED BY HUTCHINSON (1947)

Species	Genom symbol	Inclusions	Distribution
1. *G. sturtii* von Muller	C_1	*Sturtia gossypioides* (Brown) *Cienfugosia gossypioides* (Hochreutiner) *Gossypium gossypioides* (Gardner) *Gossypium australiense* (Todaro)	Central and South Australia, from Alice Springs to Broken Hill
2. *G. robinsonii* von Muller	C_2	*Cienfugosia robinsonii* (Hochreutiner) *Notoxylinon robinsonii* (Lewton)	Western Australia
3. *G. aridum* Rose and Standley	D_4	*Cienfugosia palmeri* (Rose) *Erioxylum palmeri* (Rose and Standley) *Erioxylum aridum* (Rose and Standley)	Coastal zone of Sinaloa, south to Colima, Mexico
4. *G. armourianum* Kearney	D_{2}-1	—	San Marcos Island, Gulf of California
5. *G. harknessii* Brandegee	D_{2}-2	—	Islands and coasts of Gulf of California
6. *G. klotzschianum* Andersson	D_{3}-k	—	Galapagos Islands
7. *G. klotzschianum* var. *davidsonii* Andersson Kellog	D_{3}-d	*Gossypium davidsonii* (Kellog)	Shores of Gulf of California and Revilla Gigeds Islands
8. *G. raimondii* Ulbrich	D_5	—	Departments of Cajamarca and La Libertad, North Peru
9. *G. thurberi* Todaro	D_1	*Thurberia thespesioides* (Gray)	Arizona (U.S.A.) and Sonora and South-western Chihuahua, Mexico

10. *G. trilobum* (DC) Kearney	—	*Ingenhouzia triloba* (De Candolle) *Gossypium lanceaeforme* (Miers)	Southern Mexico, Isthmus of Tenhantepec
11. *G. gossypioides* (Ulbrich) Standley	D_6	*Salera gossypioides* (Ulbrich)	Oaxaca and S. Sinaloa, Mexico
12. *G. anomalum* Wawra and Peyritsch	B_1	*Cienfugosia anomala* (Wawra) *Cienfugosia pentaphylla* (K. Schum) *Gossypium herbaceum* L. var. *steudneri* (Schweinf) *Gossypium senarense* (Fenzl.); *Gossypium microcarpum* (Welwitsch)	South-west Africa, Angola, French Sudan, Equatorial Africa, Eritrea and Somaliland
13. *G. triphyllum* Hochreutiner	B_2	*Cienfugosia triphylla* (Harvey)	South-west Africa, West Pakistan
14. *G. areysianum* Deffers	E_3	*Fugosia areysiana* (Deffers)	Southern Arabia
15. *G. stocksii* Masters	E_1		South-east Arabia, West Pakistan
16. *G. somalense* Gurke	E_2	*Cienfugosia somalensis*, (Gurke) *Cienfugosia ellenbeckii*, (Gurke) *Cienfugosia bricchettii*, (Ulbrich) *Gossypium paolii*, (Mattei) *Gossypium benadirense*, (Mattei)	British and Italian Somaliland, South to Tana River, Kenya

CLASSIFICATION OF CULTIVATED SPECIES

The wild species of *Gossypium*, i.e., those characterised by lack of lint on seed and having capsules with hairs on their sutures, are very uniform and have not been sub-divided into varieties except in the case of the Californian wild species *G. klotzschianum*. A wild type called *davidsonii*, which was originally considered as a separate species, is now believed to be a variety of *G. klotzschianum*.

The linted species have, however, undergone a greater degree of differentiation due to their spread by man in different habitats. These cultivated linted species of *Gossypium* have been sub-divided into different taxonomic units such as *varieties*, *formas* and *races* by the various taxonomists in the light of considerations that each one of them had adopted for his classification.

As already mentioned, the cultivated cottons of the world may be divided into four species, two Old World and two New World. The position in respect of their further classification is discussed below.

Gossypium arboreum L.

Hutchinson (1947) describes *Gossypium arboreum* L. as follows :

Haploid chromosome number 13, perennial much branched shrubs up to 2 m. tall, or annual *sub-shrubs* with few or no vegetative branches, 50 cm. to 1·5 m. tall. *Vegetative branches* (when present) ascending, thin and flexible. *Twigs* and young *leaves* very finely puberulent, canescent and hairy. *Fruiting branches* 2-$\propto$ jointed. *Leaves* 2/3-4/5 cut into 5-7 lobes, often with small accessory lobes in the sinus; lobes ovate, oblong or curvilinear, acute, slightly constricted at the base. *Stipules* linear or falcate, caducous. *Bracteoles* closely investing the bud and flower, more or less triangular, usually longer than broad, entire or with three or four coarse teeth near the apex ; teeth rarely as much as thrice as long as broad. *Staminal column* long, antheriferous throughout. Anther *filaments* short. *Styles* short. *Stigmas* united, rarely divided at the tip. *Capsules* tapering, profusely pitted with prominent oil glands in pits, usually three, rarely four, locular, opening widely when ripe, sutures devoid of hairs ; 6-17 seeds per loculus. *Seeds* usually with two coats of hairs, short fuzz hairs and long lint hairs, occasionally with lint hairs only (There also exist rare mutants devoid of lint).

Hutchinson and Ghose (1937) divided the species into three varieties, viz : (*i*) var. *typicum*, covering the wild and primitive cultivated perennial types ; (*ii*) var. *neglectum* comprising the more recent cultivated annual types ; and (*iii*) var. *cernuum*, including the annual big-bolled ecotypes of Assam and East Bengal hill tracts. They further showed that the development of the annual var. *neglectum* from perennial ancestors had occurred in widely separated regions and, had resulted in the formation of geographic races or forms. Accordingly, they recognised four forms in each of the two varieties,

a. Karunganni 2

b. Karunganni 5

c. Nandyal 14

d. Cocanadas 1

PLATE II

a. Gaorani 6

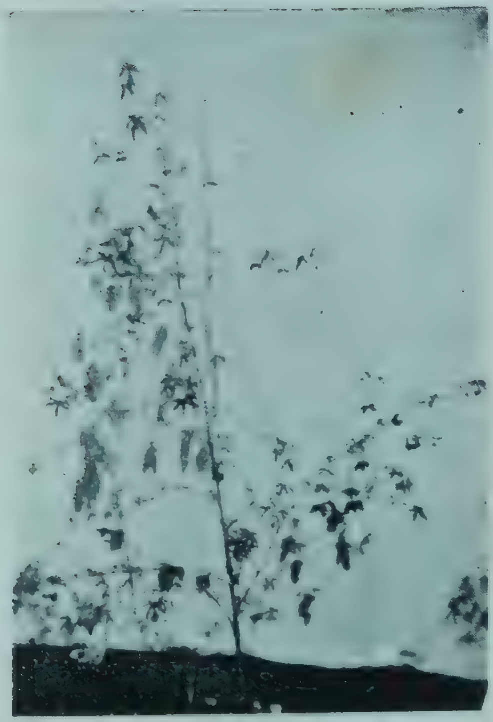
b. Virnar

c. H. 420

d. 35/1

a. C. J. 73

b. Pratap



b. Cernuum Cotton

a. Sanguineum Cotton

c. Rozi Cotton

typicum and *neglectum*. These forms were designated as forma *bengalense*, forma *indica*, forma *burmanica* and forma *soudanense* in accordance with their distribution.

Silow (1944) showed that the genetic differences between the geographic races of *G. arboreum* are much greater than those between perennial and annual types of the same race. The separation of var. *neglectum* from var. *typicum* cannot be easily made in respect of most of the taxonomic material. He, therefore, suggested the sub-division of *G. arboreum* into six geographic races, viz., (*i*) *soudanense*, (*ii*) *indicum*, (*iii*) *burmanicum*, (*iv*) *cernuum*, (*v*) *bengalense*, and (*vi*) *sinense*. A description of these six races and their geographic distribution together with the types included in each are detailed in Table 18. A few varieties belonging to this species are shown in Plates I to IV.

Gossypium herbaceum L.

It covers what Watt (1907) called 'The Levantine Species.' Hutchinson (1947) describes it as follows :

Haploid chromosome number 13. *Sub-shrubs* usually 1-1·5 m. tall with few or no vegetative branches. *Stems* thick and rigid. *Twigs* and young *leaves* usually sparsely hairy, rarely glabrous. *Fruiting branches* many jointed. *Leaves* usually flat, 1/2 cut or less into 3-7 lobes ; lobes ovate rotund to rounded, usually only slightly constricted at the base without accessory lobes between the main lobes. *Stipules* small, linear, caducous. *Bracteoles* flaring widely from the flower and capsule, rounded or broadly triangular, usually broader than long, cordate, margin serrated into six to eight broadly triangular teeth. *Staminal column* antheriferous throughout. Anther *filaments* short. *Styles* short. *Stigmas* usually united throughout, rarely cleft at the top. *Capsules* rounded, rarely with prominent shoulders, beaked, 2·0-3·5 cm. long, surface smooth or very shallowly dented, with few oil glands, 3 or 4-locular, usually only opening slightly when ripe, sutures devoid of hairs, not more than 11 seeds per loculus. *Seeds* usually bearing two coats of hairs, long lint hairs and short fuzz hairs, in rare types bearing lint only.

Hutchinson and Ghose (1937) sub-divided this species also into three varieties, viz., var. *typicum*, var. *frutescens* and var. *africanum*. They, however, did not attempt the further sub-division of these varieties into forms representing geographic distribution as was done in case of *arboreum*.

Hutchinson (1947) later classified *G. herbaceum* as under :

1. Plants glabrous or with scattered hairs on the young parts. Leaf lobes deeply constricted at basis—*G. herbaceum* var. *africanum*.
2. Plants covered with a dense even coat of long hairs. Leaf lobes scarcely constricted at base—*G. herbaceum* var. *acerifolium*.

Subsequently, however, Hutchinson (1950), on the basis of study of African forms of the species, agreed with Silow's (1944) view that the classification

TABLE 18. CHARACTERISTICS, INCLUSIONS AND GEOGRAPHICAL DISTRIBUTION

Character	Soudanense	Indicum	Burmanicum
Habit characters			
Size and general growth form	Predominantly monopodial, often subscandent	Monopodial or sympodial; sometimes subscandent if monopodial	Predominantly monopodial but sympodials frequent
Leaf and stem characters			
Hairiness of stem, petiole and leaves	Canescent or almost glabrous	Moderately hairy to almost glabrous	Usually hairy
Leaves	Seldom more than 2/3 cut, though narrow recorded	Broad 1/2 - 2/3 cut	Largely broad-leaved but narrow forms are common, laciniated
Flower characters			
Bracteoles	Small, not continuing to grow after flower has faded, half-reflexed	Small, not continuing to grow after flower has faded, considerably shorter than bolls	Variable in size, frequently large, broad and cordate; growing slightly after flower has faded; as such as long as boll
Corolla	Yellow with red spot common red (sanguineum) and white petal also occur	Yellow flowers	Mostly yellow, pale and white occur; usually red spot but ghost spot recorded
Lint and seed characters			
Lint	Lint short, usually white, low ginning	Lint short in wild forms, medium to long in cultivated types, low ginning	Very heterogenous in lint characters, coloured lint frequently
Seed			
INCLUSIONS	*G. arboreum* L. var. *typicum* forma *soudanensis* and var. *neglectum* forma *soudanensis* of Hutchinson and Ghose; *G. arboreum* L. vars. *sanguinea, neglecta, rosea* Watt. (in part); *G. nanking* Meyen vars. *soudanensis, canescens* Watt; *G. simpsonii* Watt. *G. soudanense* Watt. *G. abyssinicum* Watt; *G. herbaceum* L. var. *Perrieri* Hochr., *G. arboreum* L. (Gammie) (in part); *G. obtusifolium* Roxb. (Gammie) (in part)	*G. arboreum* L. var. *typicum* forma *indica* and var. *neglectum* forma *indica* of Hutchinson and Ghose; *G. nanking* Meyan vars. *rozi* and *nadam* Watt; *G. obtusifolium* Roxb. (Watt.) (in part); *G. obtusifolium* Roxb. (Gammie) (in part); *G. arboreum* L. (Gammie) (in part) *G. indicum* Lamk. (Gammie) (in part)	*G. arboreum* L. var. *typicum* forma *burmanica*, var. *typicum* forma *bengalensis* var. *neglectum* forma *burmanica* (in part), var. *neglectum* forma *bengalensis* (in part) of Hutchinson and Ghose; *G. intermedium* Todaro (Gammie); *G. arboreum* L. (Watt.) (in part) including var. *neglecta* Watt. (in part); *G. nanking* Meyen (Watt.) (in part) including vars. *nadam* in part) and *himalayana* Watt; *G. obtusifolium* Roxb. (Watt.) (in part); *G. arboreum* L. (Gammie) (in part); *G. obtusifolium* Roxb. (Gammie) (in part) *G. neglectum* Tod. (Gammie) (in part)
DISTRIBUTION	French Sudan, Senegal, Gold Coast, Dahomey, Northern Nigeria, Angola, Zambesi, Madagascar, Uganda, Ethiopia, Sudan, southern Arabia	Peninsular India South of the Tapti river, Saurashtra, Gujerat, Ceylon	Nepal, Bhutan, Assam, Bengal, Bihar and Orissa, eastern part of Uttar Pradesh, Burma, Thailand, Indo-China, Malaya, Dutch East Indies, Philippines

OF THE RACES OF *Gossypium arboreum* L. (SILOW, 1944)

Cernuum	Bengalense	Sinense
Essentially sympodial	Essentially sympodial	Essentially sympodial
Almost glabrous	More hairy than other races	Hairy to almost glabrous
Narrow leaf	Both narrows and broads equally common	Almost all broad
Continuing to grow after the flower has faded becoming as long as boll	Small, not continuing to grow or growing very slightly after the flower has faded	Very variable
Pale corolla common	White as common as yellow, most of them with a red spot	White, but pale common, spot may be present or absent
Predominantly white linted. Lint short, coarse, high ginning	White linted, short, coarse, high ginning	Predominantly white linted; heterogenous for other lint characters
13-17 per loculus, very long bolls		Tuft common
G. arboreum L. var. *cernuum* of Hutchinson and Ghose; *G. arboreum* L. var. *assamica* Watt; *G. cernuum* Tod. Gammie (in part)	*G. arboreum* L. var. *neglectum* forma *bengalensis* (in part) of Hutchinson and Ghose; part of *G. arboreum* L. vars. *sanguinea*, *neglecta* and *rosea* of Watt; *G. nanking* Meyen vars. *rubicunda* and *bani* Watt. (in part); Gammie's *G. sanguineum* Hassk. *G. neglectum* Tod. (in part), and *G. indicum* Lamk. (in part)	*G. arboreum* L. var. *neglectum* forma *burmanica* (in part) of Hutchinson and Ghose; *G. arboreum* L. var. *neglecta* (Watt.) (in part) *G. nanking* Meyen (Watt.) (in part) including var. *Japanese* (Watt.) *G. anomalum* Watt; *G. arboreum* L. (Gammie) (in part) *G. obtusifolium* Roxb. var. *nanking* (Gammie) (in part)
Garo hills of Assam, East Pakistan	Punjab, Rajasthan, Uttar Pradesh, Central India (Madhya Pradesh), Saurashtra, Gujerat, Khandesh, Vidarbha, Marathwada, (Bombay State) and a few small areas (recent introductions) in Madras, Andhra	China, Japan, Formosa, Manchuria, Korea

into botanical varieties was not justified and that geographical distribution had given rise to distinct races. He has, therefore, advocated that *G. herbaceum* be divided into five geographic races, viz: (*i*) race *persicum*; (*ii*) race *kuljianum*; (*iii*) race *acerifolium*; (*iv*) race *wightianum*; and (*v*) race *africanum*. The details. of the morphological characters and geographic distribution of these races together with the types included in each are given in Table 19. A few varieties belonging to this species are shown in Plates V and VI.

Gossypium hirsutum L.

This species is characterised by 26 haploid chromosomes and its other characters, according to Hutchinson, are as follows :

Small annual *shrubs* to large perennial trees. *Vegetative* branches, none to many. *Twigs* and young *leaves*, densely hairy to glabrous. *Fruiting branches* many jointed. *Leaves* small to large, cordate, 1/2 or less cut into 3-5 lobes. *Leaf lobes* broadly triangular acuminate, not constricted, but not or only slightly overlapping at the sinuses ; lateral lobes divergent, tapering to the cordate base ; they may be so broad at the base as to make the leaf appear almost parallel sided ; leaves on lateral branches in many cases entire. *Stipules* falcate, not more than 4 mm. wide and about 10 mm. long, caducous. *Bracteoles* triangular or longer than broad, cordate, gashed into usually 4-12 long acuminate teeth which are more than thrice as long as broad. *Flowers* small or large. *Corolla* forming a narrow tube (cup) or widely expanding. *Staminal column* short, antheriferous throughout. *Anthers* loosely arranged, the upper *filaments* ascending, usually longer than lower ones. *Stigmas* usually united throughout, rarely divided at the tip, never separated or spreading. *Capsules* variable in size, rounded or tapering to acuminate point, with few and inconspicuous (sometimes conspicuous) oil glands sunk beneath the smooth surface ; 3-5 locular, sutures devoid of hairs ; 5-11 seeds per loculus. *Seeds* possess copious coat of lint hairs besides a thick coat of fuzz hairs, or naked with a small tuft at the end.

Gossypium hirsutum was first sub-divided by Hutchinson (1947) into the main species, consisting of all annual forms, and two perennial varieties, viz., var. *punctatum* and var. *marie galante*. These two varieties differed from each other in their branching habits and prominence or otherwise of the main stem.

Subsequently, Hutchinson (1951) extended Silow's earlier accepted principle of intra-specific differentiation to this species also and divided it into seven geographic races, viz: (*i*) race *morrilli*; (*ii*) race *richmondii*; (*iii*) race *palmeri*; (*iv*) race *punctatum*; (*v*) race *yucatenense*; (*vi*) race *marie-galante*; and (*vii*) race *latifolium*. The characteristics and distribution of these races and the types included in each are shown in Table 20. A few varieties belonging to this species are shown in Plates VII to XII.

a. Kalyan

b. Vijalpa

a. Jayadhar

b. Selection 69

a. 170-Co. 2
(Deviraj)

b. 134-Co.2-M
(Devitej)

PLATE VIII

a. M.C.U. 1

b. M.C.U. 2

a. Laxmi

b. Buri 0394

a. 326F

b. H.14

a. M.A. 5

b. C. Indore 1

PLATE XII

a. Exotic 2 Cotton

b. Sea Island 'Andrews' Cotton

Gossypium barbadense L.

This species also has 26 haploid chromosomes and its other characteristics as described by Hutchinson are as follows :

Plant habit : perennial *shrubs* or annual *sub-shrubs*, 1-3 m. tall. *Vegetative branches* few to many, ascending. *Twigs* and young *leaves* from glabrous to densely coated with long grey hairs. *Fruiting branches* many jointed. *Leaves* 2/3 cut into 3-5 lobes. *Leaf lobes* long, tapering, acuminate, slightly constricted at base, the sinuses usually thrown into folds. *Stipules* variable in size, falcate or auriculate, caducous early or persisting for some time. *Bracteoles* almost as long as broad, cordate, gashed into usually 10-15 long acuminate teeth, which are more than thrice as long as broad. *Flowers* large, usually exceeding the bracteoles. *Corolla* not widely expanding, forming a long narrow tube. *Staminal column*, long, antheriferous throughout. *Anthers* closely packed on short *filaments*. *Stigmas* united at the top, or if cleft near the tip, never spreading. *Capsules* very large (more than 7 cm.) to very small (less than 3 cm.), 3-4 locular, broad at base or centre, usually tapering to an acute tip, sometimes prominently shouldered ; surface rough, with oil glands at the bottom of pits ; rarely almost smooth, sutures devoid of hairs, usually 5-8 seeds per loculus. *Seeds* free, bearing a copious and even coat of lint ; beneath the lint there may be a full coat of fuzz, or a tuft of fuzz, at one or both ends, or fuzz may be absent altogether.

Hutchinson (1947) recognised two varieties within the species besides the typical one. His classification is summarised below :

(*a*) Capsules large (3·5 cm. or more long); capsule surface usually coarsely pitted, or rarely finely pitted, with black oil glands in the pits. Seeds bearing a copious and even coat of lint.

- (*i*) Capsules usually *less* than 6 cm. long broadest near the base. Seed free, *G. barbadense*
- (*ii*) Capsules usually *more* than 6 cm. long, broadest near the middle and tapering to the base. Seeds connate (Kidney seeded), *G. barbadense* var. *brasiliense*

(*aa*) Capsules small (3 cm. long or less) ; capsule surface finely pitted with oil glands in the pits, almost smooth to the naked eye. Seeds bearing a scant irregular coat of lint, *G. barbadense* var. *darwinii.*

Varietal and racial distinctions in *G. barbadense* are very sharp, and its sub-division into geographic races has not been attempted hitherto.

The types included in this species and its two varieties, viz., *brasiliense* and *darwinii* together with their geographic distribution are as under :

1. *G. barbadense :* This includes *G. peruvianum* Cavanilles, *G. vitifolium* Lamark, *G. microcarpum* Todaro, *G. maritimum* and its var. *polycarpum* Todaro, *G. barbadense* var. *martima* Watt and *G. multiglandulosum* Phillipi.

TABLE 19. CHARACTERISTICS, INCLUSIONS AND GEOGRAPHICAL DISTRIBUTION

Character	Persicum	Kuljianum
Habit characters		
Size and general growth form	Small annual sub-shrubs	Very small annual sub-shrubs
Vegetative branches	Few or none	Few or none
Stem	Stiff	Slender
Fruiting branches		Developed very early
Leaf and stem characters		
Stem tip and leaf hairiness		Sparsely hairy or glabrous
Leaves	Large almost fleshy	Small, flat
Leaf lobes	Broad lobed, less than ½ cut, flat	Broad
Boll and boll characters		
Size and shape	Usually large and round, sometimes tapered and prominently shouldered pale green	Small, taper with prominent shoulders
Opening	Generally cracking and remaining closed when ripe, sometimes opening widely	Opening widely when ripe
Lint and seed characters		
Seeds	Large	Few
Fuzz	Fuzzy	Fuzzy
Lint	Copious and fair quality	Scanty and of low quality
INCLUSIONS	The typical form; Levant cotton of Watt. (1907)	*G. herbaceum* var. *kuljianum* of Russian workers
DISTRIBUTION	Iran and Baluchistan, Afghanistan, Russian Turkestan, Iraq, Syria, Turkey, Greece and Mediterannean islands. Widely spread along Mediterannean by Muslim invasion. Earliest cotton cultivated in Nile Delta	Sinkiang and western Kansu, China

of the Races of *Gossypium herbaceum* L. (Hutchinson, 1950)

Acerifolium	Wightianum	Africanum
Large, rounded perennial shrubs	Large annual shrubs	Bushy shrubs
Many	Several	Many, thin
Stout	Stout	
Usually densely hairy, sometimes sparsely	Densely hairy	Glabrous or finely tomentose on young parts
Not large	Rather large	Thin, flat
About 2/3 cut into five lobes, thick and rumpled	About 2/3 cut into five lobes, thick and rumpled	Constricted at base, sinuses between lobes open
Rather small, almost parallel sides with prominent shoulders	Rather large, parallel sided (almost) with prominent shoulders	Small, rounded
Opening widely when ripe	Opening widely when ripe or cracking and remaining closed (Wagad)	Opening widely when ripe
Small	Fairly large	
Fuzzy	Fuzzy	
Scanty, coarse	Copious, good quality	Scanty and of poor quality
G. punctatum var. *acerifolium* of Guilermin and Perrottet (1830), sensu strictu	*G. obtusifolium* var. *wightianum* of Watt. (1907) (in part)	*G. herbaceum* var. *africanum* H. & G.
North Africa, South of Sahara from Abyssinia to the Gambia and the desert oases of Egypt and Libya, Saudi Arabia, Yemen	Western India from Cutch to Madras	Portuguese East Africa South of Save river, the low Veld of Transvaal, Swaziland, southern Rhodesia and sporadically across the continent to Angola and South-west Africa. Formerly occurring as far north as the Zambesi

TABLE 20. CHARACTERISTICS, INCLUSIONS AND GEOGRAPHICAL DISTRIBUTION

Character	Morrilli	Richmondii	Palmeri
Habit characters			
Size and general growth form	Large, upright perennial shrubs	Large, lax, sprawling perennial shrubs	Compact upright perennial shrubs
Vegetative branches	10-20 ascending, often overtopping the main stem	10-20, long lax, spreading	15-20, ascending, considerably shorter than the main stem
Stem	Stiff and erect	Flexible, internodes long	Stiff and erect, internodes short
First sympodial node	17-32	13-22	20-30
Sowing date response	Strong	Considerable	Considerable
Leaf, stem and boll characters			
Stem tip and leaf hairiness	Densely hairy, hairs short	Glabrous or nearly so	Glabrous or nearly so
Leaves	1/2-2/3 cut	1/2-2/3 cut	Palmatifid, rarely lanceolate entire
Leaf lobes	Divergent, tapering	Divergent, tapering	Divergent, acuminate
Stem anthocyanin	Weak or absent	Weak or absent	Strong
Bolls	Round, not opening widely	Round, opening widely	Round, opening widely
Lint and seed characters			
Lint	White, creamy, grey or brown	Creamy	Creamy, rarely brown
Seed	Fuzzy	Fuzzy	Fuzzy
Fuzz	Green	Brownish	Brownish
INCLUSIONS	*G. morrilli*, *G. dicladum* *G. patens* and *G. contextum* of Cook and Hubbard		*G. palmeri*, *G. fructiculosum*, *G. lanceolatum*, *G. schottii* (part) of Watt.
DISTRIBUTION	Oaxaca, Morelos and Puebla States of Mexico	Isthmus of Tehuantepec, Salina Cruz, Mexico	Western Oaxaca and Guerrero State of Mexico

OF THE RACES OF *Gossypium hirsutum* L. (HUTCHINSON, 1951)

Punctatum	Yucatenense	Marie-galante	Latifolium
Bushy perennial shrubs	Small, slow growing perennial sub-shrubs	Large perennial shrubs or small trees	Annual sub-shrubs, sometimes persisting for two years
8-15, spreading or prostrate	Many, prostrate	8-20 spreading or slightly ascending, not overtopping the main stem	0-5, spreading or ascending
Flexible, bowing under the crop	Prostrate	Stout and upright	Usually upright sometimes sprawling
14-20	—	20-30	8-10
Considerable	Considerable	Strong	Slight or absent
Sparse or nearly glabrous	Nearly glabrous	Glabrous, sometimes moderately hairy	Glabrous, sparsely or densely hairy
Very shallowly cut	Very shallowly cut	1/2-2/3 cut	1/2 cut or less
Parallel sided	Parallel sided	Divergent, tapering	Divergent, broadly triangular
Moderate to strong	Slight	Usually slight, sometimes strong	Usually slight
Oval or round, opening widely	Very small, opening widely	Round or oval, opening widely	Round, oval or long, opening widely
White or brown	Grey or medium brown	White, dull grey or light brown	White, creamy, light or rusty brown
Fuzzy or tufted	Fuzzy	Fuzzy, tufted or naked	Fuzzy or tufted
Variable	Grey	Variable	Variable
G. contextum (Cook and Hubbard), *G. hirsutum* var. *punctatum* of J. B. H.	*G. ekmanianum* and *polynesian*, *G. taitense*	*G. hirsutum* var. *marie-galante* of J. B. H.	*G. latifolium* (Murray), *G. hirsutum* J. B. H.
Gulf Coast of central America and U.S.A. and Gulf Island, Africa and Asiatic countries	Yucatan peninsula of Central America	Guatemala to Colombia and Equator	All over the cotton growing regions of the world

Distribution : Tropical South America ; occasionally in central America ; South Carolina and Georgia (U.S.A.), Egypt and also southern Nigeria.

2. *G. barbadense* var. *brasiliense :* It includes *G. lapideum*, *G. brasiliense* Macfadyen and *G. pedatum* Watt.
   Distribution : Eastern tropical South America, central America and sporadic in Africa and India.
3. *G. barbadense* var. *darwinii :* It is a newly constituted variety and includes *G. darwinii* Watt, *G. purpurascens* Hooker and *G. klotzschianum* Robinson and Green.
   Distribution : Galapagos Islands.

Plate XII shows a plant of Sea Island 'Andrews' cotton belonging to this species.

ORIGIN AND DISTRIBUTION

Hutchinson and Stephens (1947) have produced evidence to show that the cultivated cottons with lint must have first appeared in the Indus Valley (the Greek name 'Sindhu' being one indication of it), and that the present *G. anomalum* is the nearest to those early cottons, which must have been introduced from southern Arabia or North-eastern Africa. Its subsequent differentiation into species and races in different areas resulted from large scale cultivation which demanded large capsules, large seed, white lint and annual habit. Two species, *G. herbaceum* and *G. arboreum* were established in the Old World complex, the former spreading to Africa, Levant countries and to the West Coast of India by sea trade, and the latter towards eastern regions. Subsequently, Hutchinson (1954) in the light of new evidence felt that this theory was untenable. It is now held that the most likely ancestor covered the bushveldt area of southern Africa stretching from Nagamiland to southern Portuguese Africa and it first gave rise to *G. herbaceum* race *africanum*. From this region, it was introduced in areas lying along the trade routes between Africa and India, viz., Arabian and Persian coasts. The perennials related to race *acerifolium* were the most primitive of the cultivated *herbaceum* and this race is found all the way from West Africa to Makran in Pakistan. This primitive *herbaceum* differentiated into race *persicum* in Persia and race *kuljianum* in Turkistan. Further, selection for annual habit in the same material gave rise to race *wightianum* in India.

Evidence has also been adduced to show that *G. arboreum* arose in cultivation by differentiation from *G. herbaceum*. This is supported by the fact that Rozi cotton belonging to *G. arboreum* race *indicum* is morphologically similar to perennial types of *G. herbaceum* race *acerifolium* occurring in Arabia. Actually, the origin and development of the species *G. arboreum* has probably been in two ways. Firstly, the cottons of race *indicum* growing in Peninsular India and including both the primitive perennial forms like Rozi and the high quality annuals of the Deccan and Madras were probably developed from the perennial *herbaceum*-like stocks of Arabia and Persia. Secondly, the *burmanicum* cottons of Assam and Burma and the related perennials found occasionally in Gangetic Valley and the neighbouring regions seem to resemble the pyramidal

forms from Madagascar. From this perennial group, arose two great annual races, the *bengalense* cotton of North India and *sinense* cotton of China.

Gossypium arboreum race *indicum* embraces the oldest forms and is closely related to *G. herbaceum*. It covers most of the commercial crop of Peninsular India. The most recent and agriculturally important of the other races, or what may be called the northern assembly, are the two annual races, *bengalense* and *sinense*, the former of which constitutes the bulk of the Indian crop.

The origin of the New World cottons has been attributed to allopolyploidy resulting from the cross of the 13 chromosome American wild species and the Old World cultivated type bearing 'A' genom. The American wild species, *G. raimondii* is probably the nearest relative of the 'D' genom that has entered into the ancestry of the present day New World, 26 chromosome, cultivated cottons. *Gossypium barbadense* is supposed to be the older of the two, having its centre of origin in Peru. *Gossypium hirsutum* appears to be a later differentiation from *G. barbadense* itself, the centre of origin being the highlands of Guatemala.

TAXONOMIC GROUPING OF INDIAN COTTONS

The Indian cotton crop consists of a large number of more or less mixed agricultural and trade varieties, which take the names of the regions or places in which they are grown. In recent years a large number of pure strains have been evolved and substituted for the mixed types. Tables 21, 22 and 23 give the classifications of these strains and varieties specieswise. It is difficult to give the exact racial position of the varieties that have been built by crossing different races of the same species. Table 24 gives the list of trade varieties which are a mixture of different taxonomic units.

TABLE 21. DISTRIBUTION AND CLASSIFICATION OF INDIAN COTTON VARIETIES BELONGING TO *Gossypium arboreum* L.

Variety	Distribution	Remarks
1. Nandyal 14	Kurnool district of Andhra Pradesh	race *indicum*
2. Gaorani 6	Nanded and Parbhani districts of Marathwada Division of Bombay State	race *indicum*
3. Gaorani 12	Osmanabad, Bhir and Aurangabad districts of Aurangabad Division of Bombay State	race *indicum*
4. Karunganni 2	Southern districts of Madras State	Cross between race *indicum* and *cernuum*
5. Karunganni 5	Central districts of Madras State	Cross between race *indicum* and *cernuum*
6. H. 420	Vidarbha Division of Bombay State, Nimar district of Madhya Pradesh and Guntur, Kurnool, Anantpur and Cuddapah districts of Andhra Pradesh	Cross between race *indicum* and *cernuum*
7. Virnar	Khandesh tract and Buldana district of Bombay State and Indore Division of Madhya Pradesh	race *bengalense*
8. Jarila	Aurangabad, Poona and Nagpur Divisions of Bombay State and Indore Division of Madhya Pradesh	race *bengalense*
9. U. P. Desi 35/1	Western parts of Uttar Pradesh	race *bengalense*
10. Pratap	Ahmedabad, Amreli and Gohilwad districts of Bombay State	race *bengalense*
11. Malvi	Indore Division except Nimar district of Madhya Pradesh	race *bengalense*
12. Malini (M. 5A)	Buldana district of Bombay State	race *bengalense*
13. Coconadas 1 and 2	Nellore, Guntur and Kurnool districts of Andhra Pradesh	race *indicum*
14. Warangal and Cocanadas	Coastal region and Warangal district of Andhra Pradesh	race *indicum*
15. White and Red Northerns	Kurnool district of Andhra Pradesh	race *indicum*
16. Mungari	Bellary, Gulburga and Raichur districts of Mysore State and Kurnool and Anantpur districts of Andhra Pradesh	race *bengalense*
17. Mathio	Gohilwad and Amreli districts of Rajkot Division of Bombay State	race *bengalense*
18 Bengals, Punjab	Punjab State, Delhi and Himachal Pradesh	race *bengalense*
19. Bengals, Uttar Pradesh	Uttar Pradesh, Bihar and Orissa States and Rewa Division of Madhya Pradesh	race *bengalense*
20. Bengals, Rajasthan	Rajasthan State	race *bengalense*

TABLE 22. DISTRIBUTION AND CLASSIFICATION OF INDIAN COTTON VARIETIES BELONGING TO *Gossypium hirsutum* L.

Variety	Distribution	Remarks
1. Indo-American 134-Co.2-M (Devitej)	Rajkot and Ahmedabad Division of Bombay State	Interspecific multiple hybrid derivative involving *G. hirsutum*, race *latifolium* and *G. herbaceum* race *wightianum*
2. Indo-American 170-Co.2 (Deviraj)	Rajkot, Ahmedabad and Poona Divisions of Bombay State	Interspecific hybrid derivative involving *G. hirsutum* race *latifolium* and *arboreum* race *indicum*
3. Mysore-American M. A. 5	Mysore State	race *latifolium*
4. Madras Cambodia Uganda 1	Irrigated summer crop of southern Madras districts and Ahmedabad and Poona Divisions of Bombay State	race *latifolium*
5. Madras Cambodia Uganda 2	Ramanathapuram and Tirunelveli and South Arcot districts of Madras State	Interspecific multiple hybrid derivative involving *G. hirsutum* race *latifolium* and *G. barbadense*
6. Cambodia 2	Irrigated and dry cold weather crop grown in central and southern districts of Madras	race *latifolium*
7. Cambodia 4	Madras and Kerala States	race *latifolium*
8. Laxmi	Mysore and Andhra States	race *latifolium*
9. Punjab-American H.14	Hissar district of the Punjab State	race *latifolium*
10. Punjab-American 216F	Hariana region of the Punjab State, western Uttar Pradesh and Tanjore delta of Madras State	race *latifolium*
11. Punjab-American 320F	Central and sub-montane districts of the Punjab State and North-western Rajasthan State	race *latifolium*
12. Buri 0394	Vidarbha Division of Bombay State and Nimar districts of Madhya Pradesh	race *latifolium*
13. Parbhani-American	Adilabad district of Andhra Pradesh	race *latifolium*
14. Punjab-American L. S. S.	Ferozepur and Bhatinda districts of the Punjab and Rajasthan State	race *latifolium*
15. Madras Cambodia	Madras State	race *latifolium*
16. Madhya Pradesh Cambodia	Vidarbha Division of Bombay State	race *latifolium*
17. Madhya Pradesh American	Indore Division of Madhya Pradesh	race *latifolium*
18. C. Indore 1	Rajasthan State	race *latifolium*

TABLE 23. DISTRIBUTION AND CLASSIFICATION OF INDIAN COTTON VARIETIES BELONGING TO *Gossypium herbaceum* L.

Variety	Distribution	Remarks
1. Vijalpa (2087)	Surat district and parts of Broach and West Khandesh districts south of Narbada of Bombay State	race *wightianum* H.
2. Jayadhar	Mysore State	race *wightianum* (contains blood of *arboreum*)
3. Broach-Vijay	Kaira, Broach, Panch Mahals, Baroda, Sabarkantha and Ahmedabad districts of Bombay State	race *wightianum*
4. Selection 69	Chitaldrug and Simoga districts of Mysore State	race *wightianum*
5. Dholleras (Wagad)	Ahmedabad and Rajkot Divisions of Bombay State	race *wightianum* (closed boll type)
6. Hyderabad and Mysore Kumpta	Chitaldrug, Raichur and Gulburga districts of Mysore State	race *wightianum* H.
7. Western Farm (Hagari 1) 8. Westerns Ordinary	Anantpur, Cuddapah and Kurnool districts of Andhra Pradesh and Bellary district of Mysore State	race *wightianum* H.

TABLE 24. DISTRIBUTION AND BOTANICAL COMPOSITION OF TRADE VARIETIES OF INDIAN COTTON WHICH ARE MIXTURES OF MORE THAN ONE BOTANICAL TYPE

Trade varieties	Distribution	Botanical constitution
1. Nadam, Bourbon, Uppam } Tinnies	Central districts of Madras State	*G. arboreum* race *indicum* *G. hirsutum* race *punctatum* *G. herbaceum* race *wightianum*
2. Madhya Pradesh Oomras	Indore Division of Madhya Pradesh and Nagpur Division of Bombay State	Mixture of varying proportions of *G. arboreum* race *bengalense* and *G. hirsutum* race *latifolium*
3. Hyderabad Oomras	Aurangabad Division of Bombay State and Telengana tract of Andhra Pradesh	Mixture of varying proportions of *G. arboreum* race *bengalense* and *G. hirsutum* race *latifolium*, the latter being about 20 per cent.
4. Central India Oomras	Indore Division of Madhya Pradesh	Mixture of *G. arboreum* race *bengalense* and *G. hirsutum* race *latifolium*, the latter going up to 60 per cent.
5. Mathio	Gohilwad and Amreli districts of Rajkot Division of Bombay State	*G. arboreum* race *bengalense* with sprinkling of *G. herbaceum* race *wightianum*
6. Comillas	Assam and Tripura States	Mixture of *G. arboreum* race *cernuum* and *G. arboreum* race *bengalense*

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CHAPTER IV

MORPHOLOGY

For a proper classification of the genus *Gossypium*, the differences and similarities between the several species comprising the genus must be recognised. The study of form and structure of cotton plants is, therefore, of fundamental importance. The work done on *desi* and American cottons grown in India regarding these aspects is very little, and, hence, the descriptions given in this chapter are chiefly drawn from the studies made by Balls (1919), Brown (1938), Hayward (1938), Hector (1936), and Spieth (1934).

The crop has a world-wide distribution covering all ranges of temperate, warm and tropical conditions. It is annual, biennial or perennial in temperate zones, while its habit is one of tall shrubs or trees in tropics. Under cultivation, it is generally annual except in some South American countries where it is still treated as perennial and kept in the field for a period of about seven years. As the range of form exhibited by the plant in different species and the countries growing it is very great, details about its various parts can only be dealt with in a broad way. A general description of these is given below.

SHOOT

In the wild state, cotton is a perennial plant and may reach a height of 15-20 feet. Most of the cultivated types, however, attain heights ranging from two to six feet. The leaves are cordate, petiolate, three to nine lobed and palmately veined. The size, texture, shape and hairiness vary a great deal. In the New World cottons, the leaves above the cotyledons occur in a regular 3/8 spiral arrangement while in the cottons of the Old World series, the arrangement is 1/3 spiral. Glands occur on leaves, bracts, petioles, stems and cotyledons. Nectaries are present on leaf calyx and bracts.

The primary axis bears two types of branches. The main stem arises from the terminal growing point, while the lateral branches arise from the axils of the leaves of main stem. The latter group consists of two types, viz., vegetative and fruiting. The former is a replica of the main stem but the latter is of a distinctive nature. Each leaf has two buds at its axil. One is placed above the base of the petiole in the middle. The other bud is situated laterally either to the right or left and is, therefore, extra-axillary in position. Axillary buds develop into vegetative branches and the extra-axillary ones grow into fruiting branches. Varieties differ in the relative activity of the two buds.

There is considerable difference between the two types of branches. The vegetative branches are more vertical and ascending while the fruiting ones

are nearly horizontal. The flowers in the latter do not appear to arise from the leaf axils but from its sides. The internodes are not straight as in the main stem but have a zigzag appearance with the leaves alternately placed. This has been described as resulting from the behaviour of a new axis which, arising from the axil of a leaf on a given axis, pushes the terminal portion of the old axis to one side creating the appearance of a lateral origin. The leaves on such branches do not have the phyllotaxy cited for the main stem, since the method of development twists the joints of the fruiting branches, orients the flower buds in an erect posture and aligns the leaves alternately in two rows. A single segment of a fruiting branch can, therefore, be said to consist of an internode, a leaf with two stipules, a flower bud and two axillary buds, of which one remains dormant while the other continues the secondary axis.

The development of the bud in axils of leaf is similar to the main stem. It produces a vegetative branch like the primary axis or a short vegetative branch bearing secondary fruiting branches. The internodes are approximately equal in length. The phyllotaxy of the vegetative branches is the same as those of the main stem. Some variation has been recorded in the development of the two types of buds in certain varieties. An irregular behaviour in the transition zone between the lower monopodial region and the upper sympodial branching was evident. In this zone either the axillary or the extra-axillary bud, sometimes neither or both, develop into their respective branching types. The nodes on the primary axis nearer the growing point have both buds developed especially when the plants are fully grown.

The economic importance of sympodial branching is great. The flowering and fruiting are dependant on the initiation of such branches and the timing of the crop for harvest is determined by the early or late production of such sympodia on the plant body. Very early varieties have their fruiting branches even at first or second node to the total exclusion of vegetative branching from leaf axils. Similarly very late varieties go on producing a very large number of monopodia before sympodial divergences appear. In such cases, the late sympodia on the main stem and the secondary sympodia arising on the monopodia will contribute to the harvests.

ROOT

The cotton plant has a slender tap root whose size and depth depend on the type of soil, the ranges of soil temperature and moisture, and the variety. The number and extent of lateral roots arising from the tap root vary. In general, they originate at about half a foot below the soil surface and extend radially to a distance of four feet, branching and rebranching profusely so as to create a net-work of roots. In some cases, a second system of laterals develo ps

at lower regions where the tap root touches the water-logged saturated soil zone.

The lateral roots appear in four to five shallow longitudinal grooves which may develop a spiral appearance due to twisting of the tap root. Subterranean shoots are reported to develop freely in the Egyptian cottons, especially in the depressions adjacent to roots. These underground shoots look like galls in the beginning and grow to various sizes before coming out as a vegetative branch.

The studies done on the rate of growth have shown that the tap roots elongate 0·9 mm. per hour at 18° C. of soil temperature and 1·25 mm. at 22° C. In unirrigated soils of America, an Upland variety reached a depth of nearly six feet while an Egyptian type grew to 10 feet 8 inches under irrigation. These limits are not general as the depth of root penetration in other zones with other varieties has not gone beyond two feet. The growth of tap root is affected by excessive moisture, hard dry soil layer and degree of soil alkalinity. The lateral roots behave in the same way under the play of similar factors but adjust their quantum to the plant spacings and soil moisture ranges. Under conditions of water saturation and submersion, the laterals get asphyxiated and die but are regenerated when the optimum conditions reappear. Apart from the soil type, the main factors which have a direct influence on root growth are temperature, moisture and aeration in the root zone.

The primary root is usually an exarch with a tetrarch radial protostele (Plate XIII). The spiral thickenings of the protoxylem get longitudinally stretched as the axis matures and the walls collapse. The metaxylem in the centre of stele consists of four or eight tracheae which are occasionally separated by smaller xylem showing scalariform thickenings. The metaxylem develops centripetally and does not reach maturation in the central portion until the secondary thickening is initiated. Four groups of phloem alternate with protoxylem and are separated from the central metaxylem by parenchymatous cells. Thickened phloem cells are formed near the cambial initials when the primary root matures. The pericycle is of two or three layers of cells over the protoxylem elements and of a single layer of cells over the phloem region. The endodermis which is composed of one layer of cells is approximately of the same length as the pericycle cells. The cortex includes the endodermis and a number of concentric layers of parenchymatous cells which are usually isodiametric. Epidermis consists of a single layer of cells.

Secondary thickening begins very early with the cambial activity in the zone of the fundamental parenchyma situated between the central metaxylem and primary phloem. The parenchyma forms rays of cells which are radially elongated and which become irregular owing to their increase in size. Outside the cambial zone, the secondary phloem has a characteristic appearance which arises out of the differentiation of small, thick-walled pholem fibres.

Generally, the secondary phloem rays are centripetally continuous with secondary xylem rays but in rare instances, they may be pericyclic in origin. The cortical and epidermal cells get stretched and disintegrated with the growth of root, leaving the pericycle active and free to produce a multi-layered periderm functioning as a protective cover to the mature root.

In the hypocotyl of a five-day old seedling, the vascular pattern of the portion one centimetre below the soil level shows the beginnings of a change from the exarch condition of the root to the endarch state of the shoot. At the cotyledonary node, there is very little differentiation of tissue indicating thereby that this region is really the older part of the growing axis. The first transition is visible in the place where metaxylem differentiates in a ring ; higher above, parenchyma is differentiated between the metaxylem elements forming typical protoxylem-metaxylem transition bundles ; at the next higher level, the protoxylem elements of each bundle differentiates as two rows of spiral cells formed at right angles to metaxylem and separated by parenchyma; further up the axis there is centripetal differentiation of protoxylem and centrifugal differentiation of metaxylem approximating the endarch condition ; a little higher above the hypocotyledonary plane, the rays bisect the transition bundles and widen them out so as to have one half of each bundle lying on either side of the hypocotyledonary axis; and at the level of the cotyledonary leaves, the four units of the original transition bundles diverge into their respective cotyledons (Plate XIV).

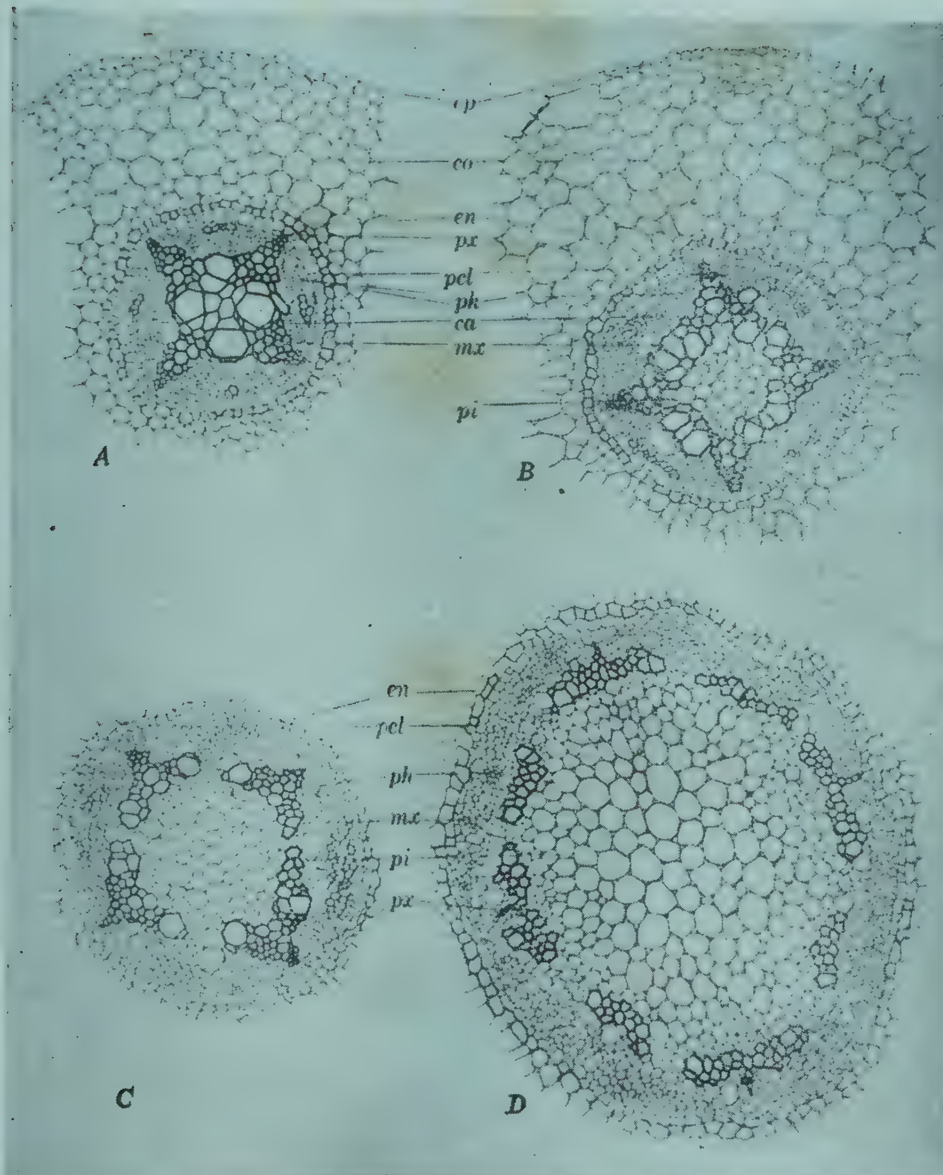
STEM

The primary axis is erect and branched. Its height varies according to varieties, season of planting and type of cultivation. The growth curves reveal that sunshine has an inhibiting effect and that the prevailing night temperature controls the rate until the small hours of the morning, provided there is no water stress. Experiments in the Sudan have shown that elongation of nodes is dependent on water supply while the production of new nodes is determined by nitrogen levels. The fall in growth rates noticed in the latter half of the season is attributed to the deflection of carbohydrates from the apex of the plant and the lateral apicies of branches, to the developing bolls. In general, the growth of the main stem which follows the 'compound interest law', falls off without keeping up to the exponential growth pattern soon after the initiation of the first flower.

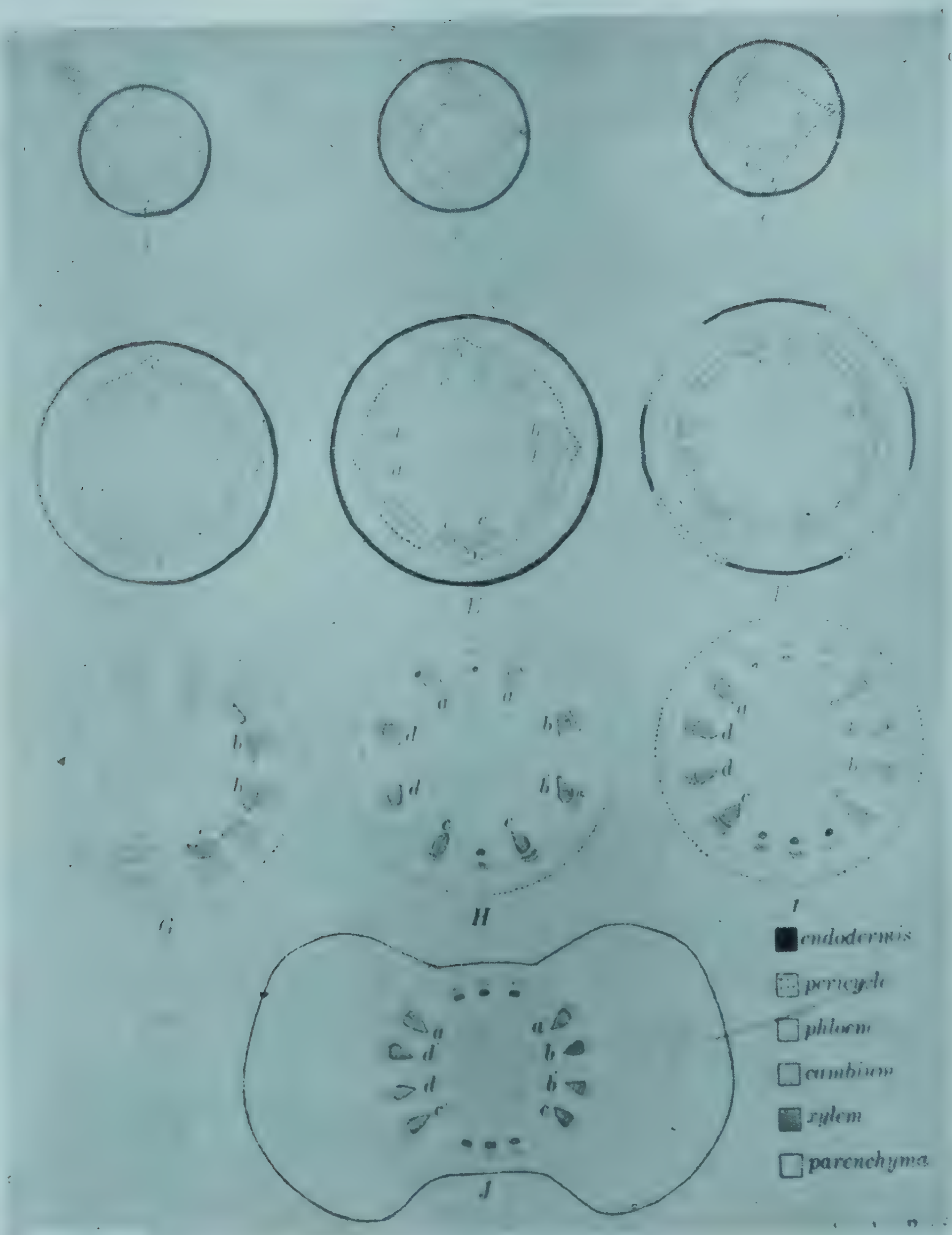
The stem is irregularly ridged with three to five large bundles and many smaller ones located in the vascular cylinder. The pith is made up of thin-walled parenchymatous cells. The stelar tissue being compact, gives the appearance of a continuous cambial zone. The primary xylem is endarch and radially aligned with the secondary xylem. The phloem is differentiated collaterally in relation to the xylem. The inner cortical region is composed of thin-walled cells which compensate for the increasing size by tangential

enlargement and radial division. Small compact collenchymatous cells often extending to the epidermis form the intermediate zone where a number of lysigenous glands develop in thin-walled tissue nearest the epidermis (Plate XV). It is reported that the glands exposed to light contain quercitin, ethereal oils, resins and tannins while others not exposed to light contain gossypol. The epidermis is a single layer of uniform compact cells with the outer walls overlaid by a cuticle. Numerous stomata are found on the epidermis. Two types of epidermal hairs — one long and unicellular and another short and multicellular (probably glandular)—are produced. As the stem matures, the epidermal and cortical regions get fissured and covered by phellogens. The outer layers of the axis become corky; lenticels are formed; thick-walled fibres are produced in the secondary phloem ; and the soft woody tissue gets disintegrated.

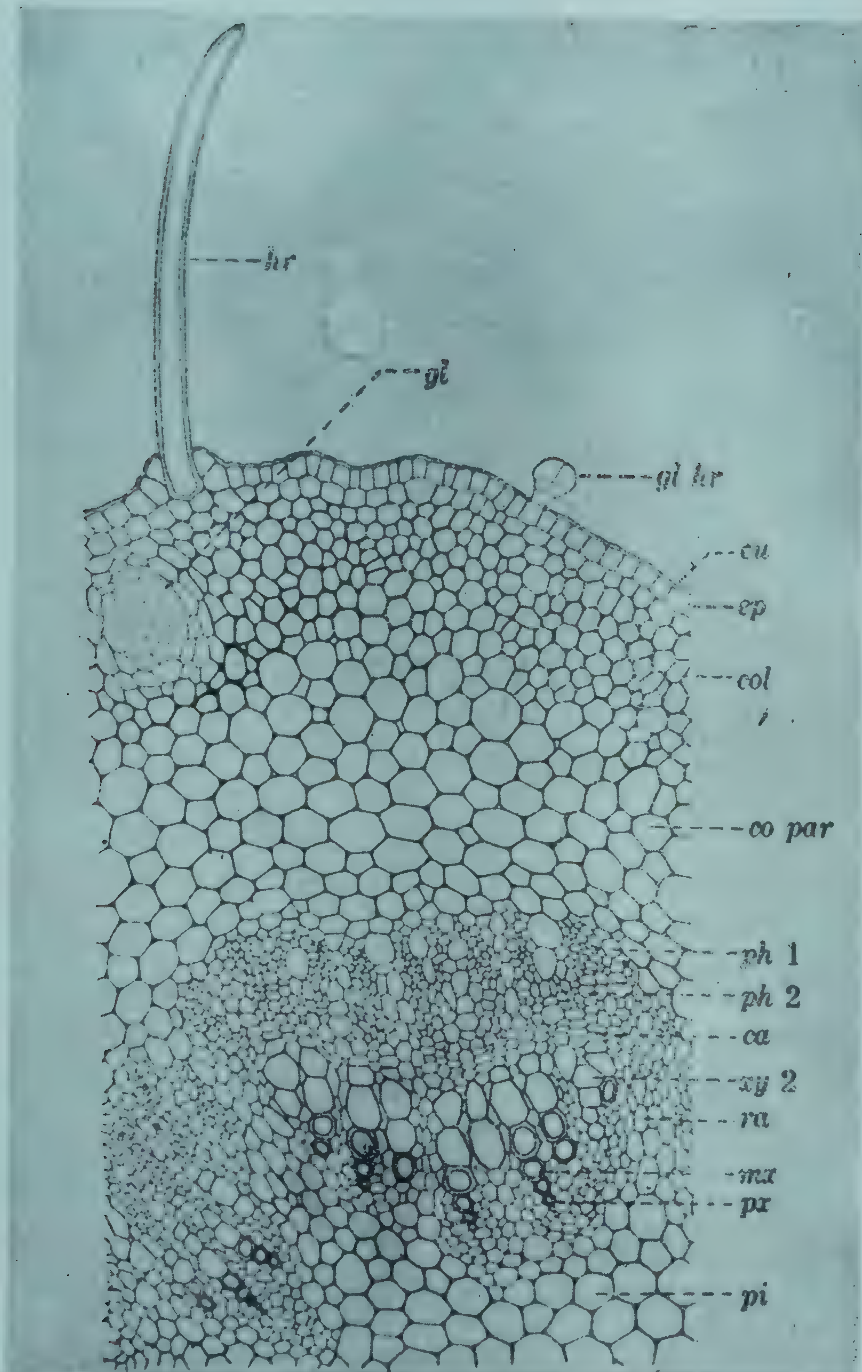
The vegetative branches and the main stem develop as a result of the activity of the terminal meristem of each axis. Such growth named monopodial is in contrast to the sympodial one found in fruiting branches. Gore (1935) has described in full with illustrations (Figs. 8 and 9) the ontogeny of the fruiting axis as well as the development of buds in the leaf axil on a fruting sympodium. According to him, "a single segment of a fruiting branch consists of an internode, a leaf with stipules, a flower bud, and two axillary buds, one of which remains dormant and becomes the axillary bud of the fruiting branch while the other continues the secondary axis. The fruiting branch of cotton is made up of a series of these segments which gives to the entire structure a jointed appearance. The first evidence of the development of a fruiting branch is a primordium which occurs in the axil of a leaf on the main stem at the second or third node back from the apical meristem. This axial primordium is early differentiated into two separate growing points ; one grows faster and becomes the fruiting branch primordium ; the other grows slowly and develops the axillary bud on the main axis, which is homologous with the axillary bud of the fruiting branch. The fruiting branch primordium becomes raised at three points where the first leaf and stipules are to arise. At this stage a single primordium exists which resembles the apical primordium of the main stem. After the leaf and stipule primordia are definitely differentiated, it begins to grow away from the subtending leaf and is directed away at an increasing angle. It becomes bluntly conical in shape and projects beyond the subtending stipules continuing its development into a flower bud. At this time, a zone of tissue becomes active between the leaf and the primordium of a flower. It soon develops two unequalised growing points, the smaller of which gives rise to the axillary bud ; the larger one continues the fruiting branch by developing a leaf and stipules for the next axis. By a repetition of this process the fruiting branch comes to consist of a series of axes, each axis made up of a single in-



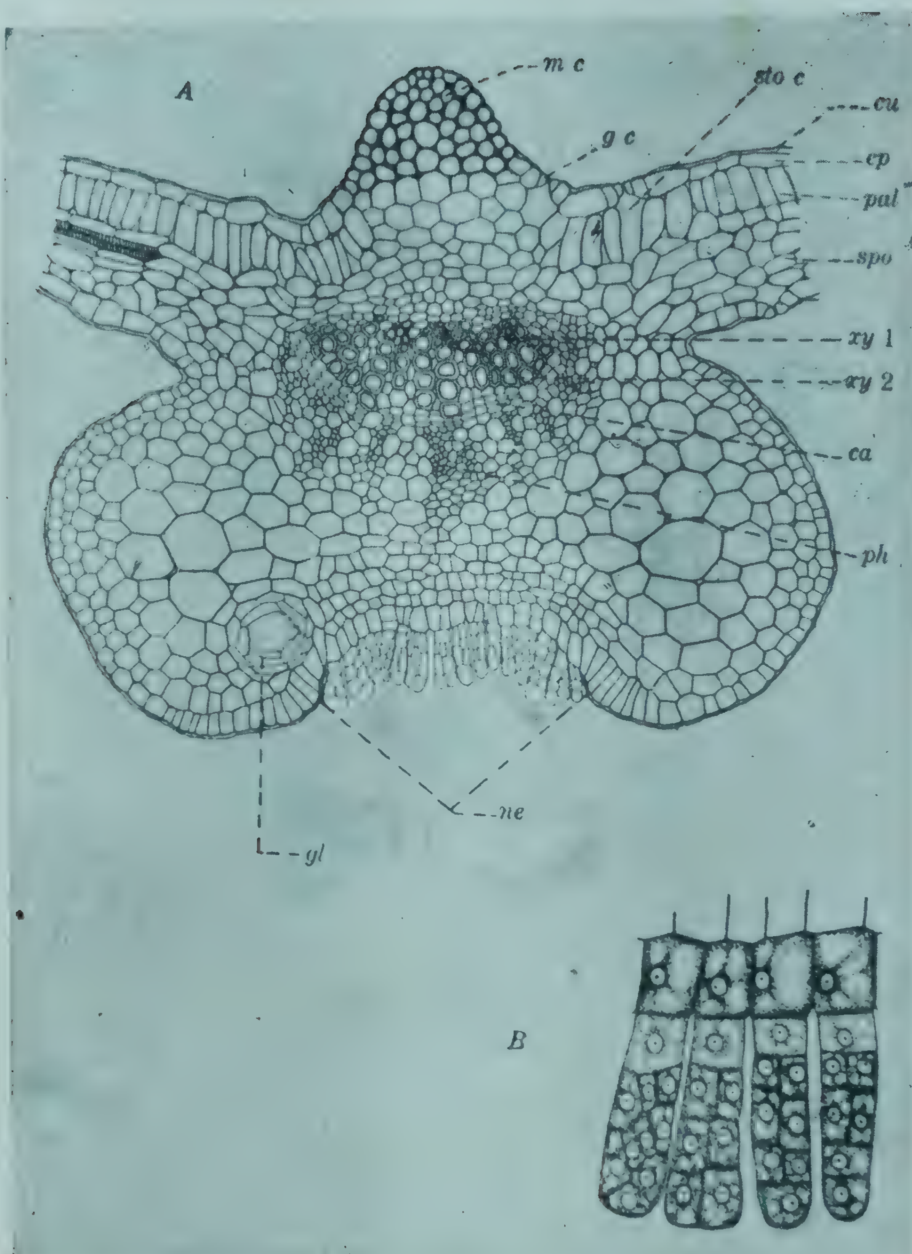
A, transection of primary root; B and C, of lower hypocotyl; D, of middle hypocotyl; *ca*, cambium; *co*, cortex; *en*, endodermis; *ep*, epidermis; *mx*, metaxylem; *pcl*, pericycle; *ph*, phloen; *pi*, pith; *px*, protoxylem. (After Spieth).



Diagrams illustrating vascular transitions: A, transection at root level; B and C, lower hypocotyl; D and E, middle hypocotyl; F-I, upper hypocotyl; J, cotyledonary node (After Spieth).



Transection of portion of young stem; *ca*, cambium, *col*, collenchyma; *co par*, cortical parenchyma; *cu*, cuticle; *ep*, epidermis; *gl*, gland; *gl hr* glandular hair; *hr*, hair; *mx* metaxylem; *ph 1*, primary phloem; *ph* 2, secondary phloom; *pi*, pith; *px*, protoxylem; *ra*, medullary ray; *xy* 2, secondary xylem. (After Hayward).



A, transection of portion of mature leaf through main vein; B, detail of papillae in nectary; *ca*, cambium; *cu*, cuticle; *ep*, epidermis; *g c*, guard cell; *gl*, gland; *m c*, mechanical cells; *ne*, leaf nectary; *pal*, palisade cells; *ph*, phloem; *spo*, sponge cells; *sto c*, stomatal cavity; *xy 1*, primary xylem; *xy 2*, secondary xylem. (After Hayward).

ternode and each terminated by a flower. Cottons in which a sympodium consists of more than one internode are exceptional. Early in the development of the fruiting branch, when the first fruiting axis is being formed, it is pushed to one side so that the developing structures are projected to one side of the leaf on the main stem. Thus a fruiting branch is more nearly horizontal with the primary axis and grows out either to the right or left of the subtending leaf on the main stem."

In regard to the axillary leaf buds on fruiting branches, he opines that "the first divergence from the axillary bud primordium is a bract-like structure, unattended by stipules, possibly representing a reduced leaf and stipules. There next arise a leaf and stipules for the second node, followed by the turning aside of the growing point and the development of a sympodium. The new terminal primordium develops a monopodial axis at the next node, however, and at a succeeding node another sympodial axis and a monopodial axis may continue until three or four flower primordia are produced."

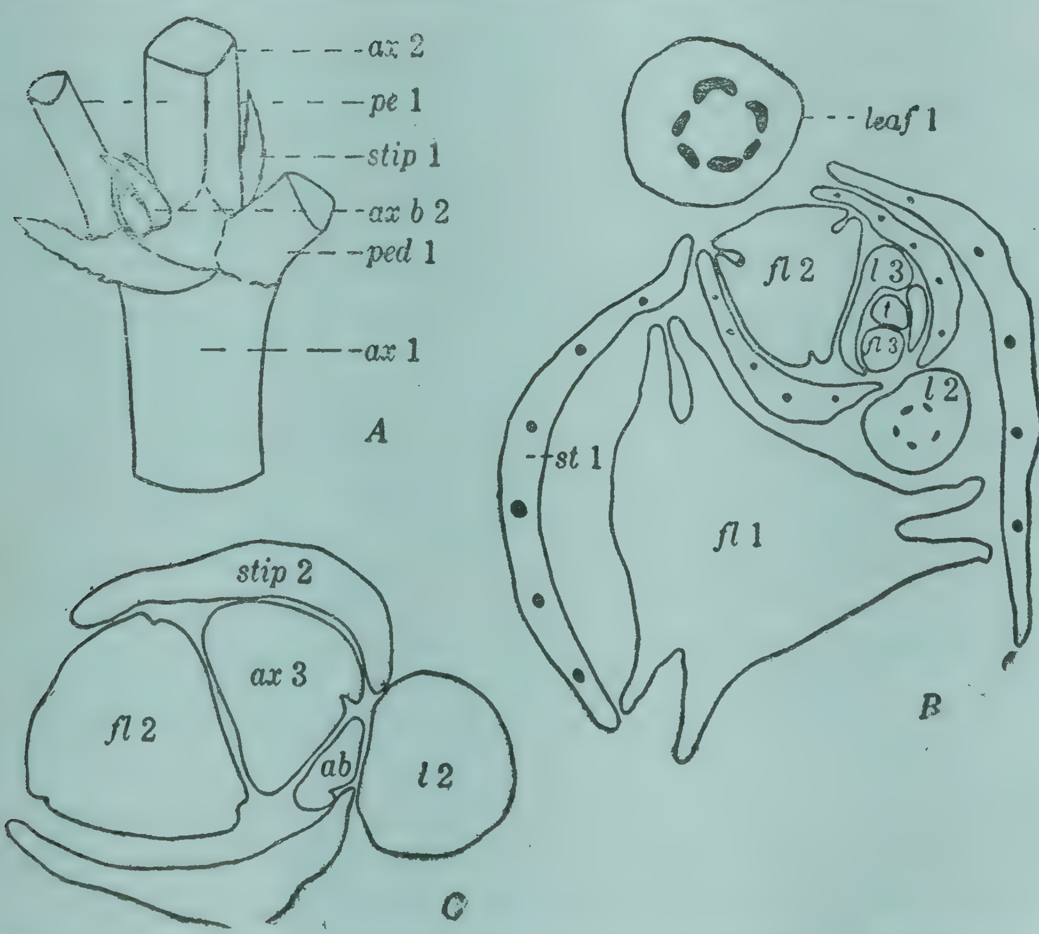


Fig. 8: A, portion of fruiting branch showing parts of two sympodia. The termination of axis 1 is the flower whose pedicel is shown, together with leaf and stipules; ax 1, 2; axes 1 and 2 ; *ax b* 2, axillary bud developed from axis 2: *pe* 1, petiole; *ped* 1, pedicel of flower; *stip* 1 stipule; B, Outline of transection of terminal bud of fruiting branch showing three sympodia and terminal of fourth axis (axillary fruiting branches not shown); *fl* 1, 2, 3: *1*, 1,2,3; *st* 1: and *t* flowers, leaves, stipule, and terminal for respective sympodia; C, lower level on sympodia 1 and 2 with greater enlargement: *ab*, axillary bud of axis 3, *ax 3*. (After Gore).

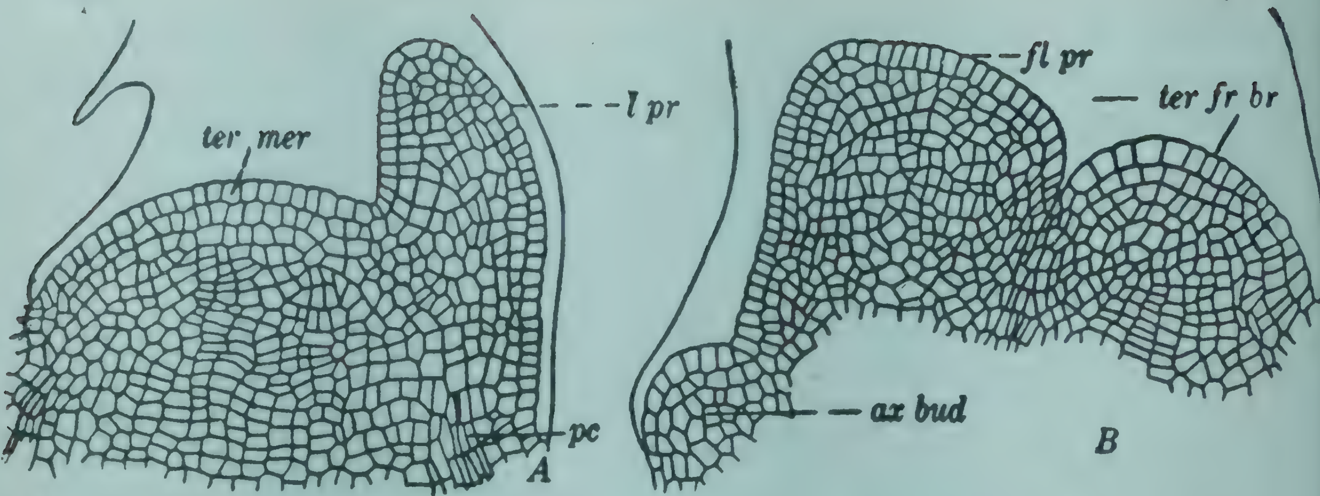


FIG. 9: A, longisection of apex of main axis; B, same of fruiting axis; *ax bud*, axillary fruiting branch bud; *fl, pr*, flower primordium, *1 pr* leaf primordium; *pc*, procambium; *ter fr br*, terminal fruiting branch; *ter mer*, terminal meristem. (After Gore).

LEAF

The leaves are spirally arranged on main stem and the vegetative branches. The arrangement on the sympodia is in the form of alternate rows. The phyllotaxy of the American cottons is 3/8 while that of the Asiatic varieties is 1/3. The leaves are petiolate and stipulate. The petioles are glabrous, pubescent or fully hirsute depending on the variety. The shape of the leaf is generally cordate (entire in many wild species) and the lobing is palmate. The number and depth of sinus in lobes vary. In *barbadense* varieties, the leaves are large with lobes deeply incised ; in *hirsutum* group, they are big with lobes cut to about half to one-third the length ; and in Asiatic types, the leaves are small and the lobes are rounded or very deeply cut. The deepest lobe is found in the Okra leaf. The leaf surface may be hairy or glabrous. Nectaries are found on the undersides of the main veins. Multicellular hairs of epidermal origin have been recorded on the leaf surface. The colour of the leaf may vary from light green to full green. Some varieties develop a red pigment masking the full green as in red *arboreum* types. A pink spot of variable intensity at the junction of the petiole and the leaf is the feature of many *arboreum* and *hirsutum* varieties.

Stomata occur on both sides of the leaf, but they are more numerous on the underside. In the Egyptian variety, the lower epidermis contains 116 to 176 stomata per square millimetre while the upper epidermis has 44 to 97. Two conspicuously thickened guard cells surround each stoma. Stomata are also found in cotyledons and hypocotyl.

The upper epidermis consists of brick-shaped cells whose outer walls are cutinised. The cells in the next palisade layer are very much elongated. The spongy cells below the palisade have numerous intercellular spaces. Near the midrib, lysigenous glands, extending sometimes from the lower epidermis

to the palisade layer, are found. The lower epidermis is similar to the upper (Plate XVI). The American cottons have a palisade above with a spongy parenchyma below, while the Asiatic varieties have palisades both on the upper and the lower sides. The parenchyma in the latter varieties is, therefore, very much reduced.

The veins have ribs like projections consisting of strands of thick-walled mechanical cells. The vascular bundle present in them is collateral resembling the stem.

Nectaries are present on the abaxial surface of the main ribs of leaf. The common number is one to three though it may vary from one to five. They have the appearance of shallow pear-shaped naked pits, sometimes canopied by stellate hairs arising from the surrounding surface. Papillae made up of several glandular cells arise from the floor of the pit. The papillae are epidermal in origin and are formed by successive transverse, vertical and periclinal divisions.

The leaf petiole has its vascular bundles arranged in a ring on account of its compressed oval form in transection but in general anatomy, it is very similar to the leaf.

Gore (1935) describes and illustrates (Plate XVII) the early development of leaf and stipules as follows :

"The leaf primordium and stipule primordia arise practically simultaneously from the apical meristem of the primary axis. The leaf primordium is rounded and collar-like at first, later tapering somewhat up to the rounded tip. As the embryonic leaf grows upward it becomes bluntly pointed. There is little evidence of differentiation into petiole and blade at this stage, except the slight beginning of the plicate folding characteristic of the lamina of a young leaf. No epidermal hairs are present at this stage, although they begin their development early. The third young leaf from the tip is completely covered with them.

The tip of this first protuberance becomes the median lobe of the palmate leaf ; its base develops into the petiolar region. There soon develops on the slightly incurved margins of this primordium two pointed protuberances, located about halfway between the tip and its base. These are the primordia of the two lateral lobes of the leaf. The young leaf, consisting of three lobes, now proceeds to develop in length with continued inward plicate folding and as the lobes increase laterally in size, forms a cup-like portion. If additional lobes occur, they arise in the same way and are similar in all respects. Seven lobes is the usual number for leaves on the main axis, while on the fruiting branches of Pima and Sea Island varieties, the leaves usually have three. In Mebane, five-lobed leaves are commonly found on the fruiting branches. Soon the tips of the individual lobes meet and the lamina develops rapidly. The main veins appear as definite ridges on the abaxial

surface of the leaf and are very thick in proportion to the rest of the leaf. The venation is palmate.

Simultaneously with or shortly after the initial leaf primordium becomes distinct, two stipular flanking protuberances arise. These are pointed and concave at first, but as they grow they widen out from the base somewhat, later become toothed, fold inward very slightly and keep pace with the growth of the leaf. They are not folded or plicate as is the young leaf but remain more or less flattened, their interlocking hairs holding them tightly appressed to leaves."

Balasubrahmanyan (1952) noticed that the leaf-shape development of the triploids and hexaploids derived from the hybrids made between 13 chromosome wild cotton *G. raimondii* and the cultivated variety of 26 chromosome *G. hirsutum* race *latifolium* was very characteristic in the fruiting branches and different from the normal behaviour. The leaves on the fruiting branches of triploids were mostly entire like *G. raimondii* while the leaf of the tetraploid *G. hirsutum* race *latifolium* was always found on the main stem subtending the branches. In the hexaploid, the entire leaf of *G. raimondii* appeared only at the nodes of secondary fruiting branches carrying flower buds but not in others. The phenomenon was considered to point to a definite evolutionary trend which was not clear at present.

FLOWER

The flowers are extra-axillary, terminal and solitary. On account of the sympodial development of fruiting branches, the flower opening follows a spiral course in acropetal and centrifugal succession. The innermost bud of the lowest and oldest branch is the first to open while the outermost bud of the highest and youngest branch is the last to do so.

The flower is subtended by an involucre of usually three unequal leaf-like bracts which may be free as in the American cottons or united as in the Asiatic varieties. They are generally large, ridged, entire or toothed corresponding to the principal veins. Characteristic stellate hairs are found on the outer surface. Bracteoles, alternating with the bracts on the inside of the involucre or standing on either side of the small bract, may be present. Extra-floral nectaries occur sometimes on the apex of the peduncle below the auriculate base of the bracts.

The calyx is persistent and shaped as a shallow cup. It consists of five undiverged sepals with the lobes variable in size, short and broad (occasionally long and pointed). The calyx adheres tightly to the base of the boll as it develops. In certain varieties, three extra-floral nectaries, irregularly triangular in shape and surrounded by stiff hairs, are present in the outer calyx. The sepals possess a number of globular sub-epidermal glands in irregular rows. Inside the calyx, five greenish obovate or spatulate organs rudimentary and small in size are frequently seen alternating with the lobes. These in-

tercalicary organs have been interpreted as supernumerary 'calyx lobes' or 'free stipular elements.'

The corolla is tubular, consists of five obcordate petals alternating with calyx lobes and overlapping the next one in the series in a convolute manner. The petals may be white, creamy white, light yellow, yellow or purple in colour. In some varieties, a spot of purple, sometimes called 'eye', is found on the claw (base) of the petals. This anthocyanin pigment may vary in intensity and extent. The first day after the anthesis, the corolla changes into pinkish hue and then into red during the succeeding day. It withers and falls off on the third day, together with the staminal column and stigma leaving the ovary, calyx and involucre intact.

The stamens are numerous and united to form a tubular sheath which surrounds the pistil except for the exposed portions of the style and stigma at the top. The filaments though appearing to arise in five fascicles really contain 10 well-defined groups of stamens in approximately vertical rows. The anthers are reniform, bilocular, dehisce along a single line over the crest of the anther and liberate spinose pollen grains. The exine of the pollen is markedly sculptured and possesses numerous germ pores.

The pistil consists of three to five undiverged carpels corresponding to the locular composition of a fully mature dehisced boll. The ovules are attached to the parietal placenta of each loculus. The style varies in length and splits near the apex into three, four or five parts depending on the number of carpels. The dehiscence of the boll is along the dorsal sutures.

The meristem of the terminal bud gives rise to the primordia of the involucre, calyx, corolla, androecium, and gynoecium in acropetal succession. The three bracts appear first as crescentric primordia, the first one arising opposite the leaf. They develop serrate margins and grow in size forming a triangular bud closing the other parts of the floral organs until the withered flower after anthesis forces them apart and leaves them free to come back to the original position for protecting the growing fruit. The extra-floral nectaries of the involucre are formed late.

The calyx primordium arises as an undulating ring of meristematic tissue, and grows upward, differentiating five crescentic protuberances which become later the tips of the five-lobed gamosepulous calyx. Inequalities in growth at the apex and base of calyx give rise to the undulating rim, shallow cup, constricted throat and dilation of the basal portion. Later at the time of anthesis, the growth rate is reversed and the throat becomes enlarged.

Next to the divergence of sepal primordia, a common stamen-petal primordium is formed. It develops first as a ring collar taking a shape of saucer-like depression with a thick marginal rim. Five narrow crescentric points arise on this margin and differentiate into petals. Each petal primordium develops an apical notch and the two halves grow at unequal rates. The

shorter half is glabrous while the other is hairy. The interlocking of hairs keeps the petals together in the convolute bud.

During the formation of petals, the inner margin of the meristematic ring grows upward, forms five protuberant ridges and produces five fascicles of stamen-primordia. Further development results in the formation of ten paired ridges with the lobes alternating with petals. Multiplication by division produces large number of stamens. The anthers get crowded and packed losing their natural orientation. There is little elongation of the filament in the beginning but it lengthens rapidly prior to blossom state.

The primordia of carpels arise from the growing point surrounded by staminal column but they become later the stylar and stigmatic parts of the pistil. The growth is slow at first, and the fast-growing ovary pushes the stylar structures into the staminal tube very soon. The inturned margins of the undiverged carpels grow centripetally and upwardly until the ovarian cavity is divided into locules equal to carpel. The reflexed margins of carpel grow into placentae, on which ovules arise.

As the ovary enlarges due to the functioning of the false septum in each carpel as cambium, the edges of the placenta get adpressed to the edges of the septa. These layers become lines of weakness in mature capsule and lead to the loculicidal dehiscence of the fruit. The tip of the style continues to grow and project into the staminal tube differentiating into conducting tissue for pollen tube growth and stigmatic surface with hairs at the exposed region.

The vascular system of the floral axis is very similar to that of the stem forming 20 to 30 bundles. The pedicel is triangular in transection at the involucral node. Two main bundles of each bract diverge from the vascular ring and pass into bracts at higher level. Above this point, there is an inward divergence of a series of vascular strands leading to the formation of placental bundles. At a higher level, there is a divergence of a series of bundles supplying the outer boll wall, the number varying with the number of carpels. Five or more bundles supply each sepal, three or more to each petal and ten main bundles for the staminal column (Fig. 10). All these are successively diverged.

The vascular anatomy of the flower in the region of thalamus and gynaecium was studied by Abraham (1937). He found the pattern of vascular bundle arrangement in these regions to be constant for a variety. The number of vascular stands in wild cottons is very much fewer than in cultivated types ; the bundles range themselves under two categories in Asiatic cottons ; they are grouped together in definite patterns in *G. herbaceum* while there is no regularity in *G. arboreum*; the New World cottons are divisible into three broad groups ; the floral anatomy of *G. herbaceum* resembles very closely *G. hirsutum:* the wild species *G. stocksii* is nearer to *G. arboreum* than *G. herbaceum* in its anatomical set up ; two sub-groups in *G. herbaceum* and three in *G. arboreum* are distinguishable.

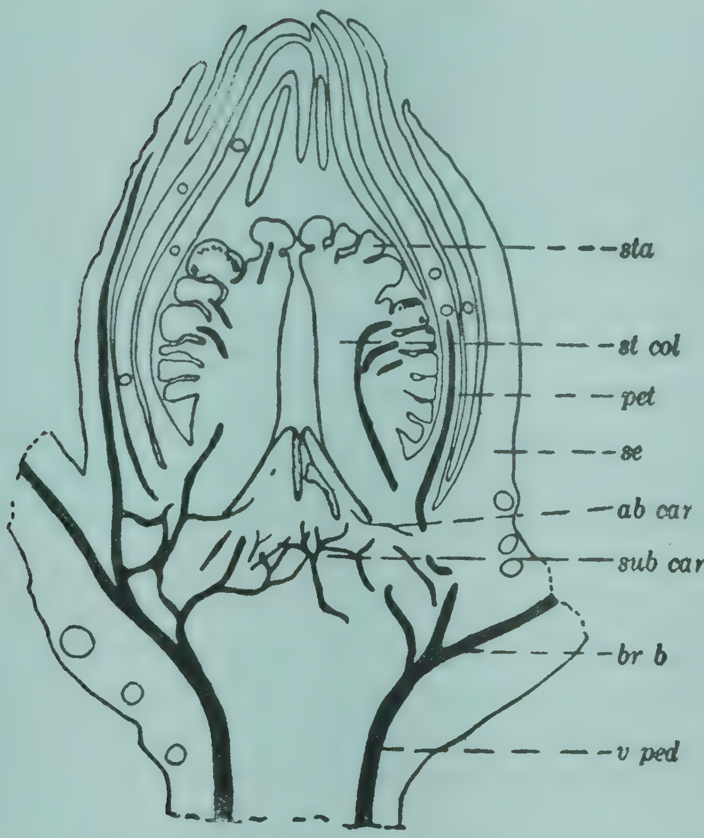


FIG. 10: Longisection of flower bud showing vascular supply to various organs. The variety is Mebane; *ab car*, abaxial carpellary bundle; *br b*, bract bundle; *pet*, petal; *se*, sepal; *sta*, stamen: *st col*, staminal column; *sub car* subcarpellary complex: *v ped*, vascular supply to pedicel. (After Gore).

The boll opening was correlated to anatomical structure. It was found that the mid-dorsal bundle of the carpel divides generally at the base into two branches which run parallel, and that dehiscence takes place along definite lines differentiated by the formation of special layers of cells between the branches of the mid-dorsal bundle. Cleavage also takes place in the placental axis along lines similarly differentiated. If the extent of formation of these lines is limited by any cause, 'bad boll opening' results. In varieties of *G. arboreum* race *indicum* grown in South India, 'bad opening' was traced to the intra-carpellary fusion of the placental bundles which extends to a much higher level than in other cottons, thus limiting the length of dehiscence along the placental axis. In Wagad cottons the bolls open intermittently and only to a very slight extent. This is brought about by the coalescence of the two branches of the mid-dorsal bundle at frequent intervals, which feature delimits the formation of the dehiscence line in certain portions of the mid-dorsal line.

The existence of an upper stelar vascular tissue is found to be a feature of many cottons. Considerable variations are found with regard to its occurrence and in the length of its extension from variety to variety, plant to plant

and flower to flower. In varieties where this tissue is prominent, proliferations are found to occur on the apex of the floral axis, above the level of the carpels. The usual types of proliferations are prolongation of the floral axis, production of supernumerary carpels and bolls and extra-carpellary ovules. Occurrence of such proliferations on the apex of the floral axis seems to point out that the upper stelar vascular tissue in cotton is really the extension of the floral vascular stele and not 'discarded' 'superfluous' tissue. The ovule situated in line with the region of intra-carpellary fusion of the placental bundles has always been found to abort even in the primordial stage. From a study of the early development of this ovule, it is concluded that its suppression should have occurred at the time of the fusion of the bundles. The abortion of this lower-most ovule seems to be partly responsible for the higher number of lint hairs produced on the seed just above it on the same placenta.

FRUIT

The development of the fruit (boll) begins with the fertilisation, and shedding of withered floral organs enclosing it. Workers in Egypt recorded an increase of one millimetre in diameter per day, the attainment of full growth by twentyfifth day and the dehiscence by the fortyeighth day. These figures are not universal, as differences in varieties and environments vary the rates and periods required to reach full maturity. Bolls developing under falling temperature will need more days to mature than those growing under rising temperature. These factors induce a difference of nearly five days in maturation periods between very early and very late bolls produced on the same plant. Bolls of Sea Island and Meade cotton grown in South Carolina took 57·6 and 56·1 days, respectively, to attain full maturity. The big-bolled American types under cultivation in India take about 55 days while the Asiatic varieties require only about 45 days which may get further reduced to 35 days under higher soil and atmospheric temperatures. It may, however, be stated that the first half period of maturation of a boll is spent in growth and the second half in internal development without any changes in the boll size.

The ripened boll contains seeds varying from one to nine in each loculus. Except in the Asiatic variety grown in Assam under the name of Garo Hill cotton which may have as many as 17 seeds per loculus, majority of others grown in India have only up to seven. A fair percentage of the seeds remain undeveloped due to non-fertilisation, heredity and environment. These are called 'motes'.

SEED

The full-grown seed is irregularly pear-shaped, varying in size depending on the variety and conditions of growing. It may be naked or bear short hairs called 'fuzz'. All cultivated cottons bear long fibres named 'lint' and a

majority of them have also fuzz on the same seed. The lint is removed by gins while the fuzz remains attached. The colour of fibres may be white, brown or green and that of the seed is usually grey, brownish or black.

The mature seed has two cotyledons folded up and occupying the entire portion of its cavity. They are broad and kidney-shaped. The seeds when planted in the soil take about four to six days to germinate depending on the prevalent temperature and moisture. Weak and abnormal seedlings come out of the soil up to 15 days, but they never catch up with the growth or yield of normal plants. The primary root pushes its way through the micropyle into the soil and the arched hypocotyl, in the process of straightening up, lifts the convoluted cotyledons out of the ground. The cotyledons on being freed from seed coat expand rapidly and the growth of the epicotyl elongates the axis.

Balasubrahmanyan and Ramasami Mudaliar (1933) working with inter-specific and inter-racial crosses of Asiatic cotton found delayed germination in seeds obtained from the former. The causes were traced to hard seed coat, closed micropyle and partially filled cotyledonary-*cum*-embryonic contents. The first two retarded the passage of water required for germination while the ill-developed contents were unable to smell rapidly and exert the requisite pressure for the early rupture of the hard coat necessary for the proper emergence of the plumule. The germination increased when the seed coat thickness was reduced by treatment with sulphuric acid or by abrasives or by partial removal at ends.

SEED HAIRS

Lint and fuzz represent the outgrowths of epidermal cells on seeds. Some cells continue to lengthen while others stop growing after a time. The former are the lint and the latter the fuzz. Balls (1915) stated that no lint hair differentiation from the epidermal cells took place after the first day of flowering and any differences noticed in ginning outturn of the bolls harvested late must be due to the variations in the number of hairs which sprouted on seed coat. Environment was cited as the main factor of influence. Gulati (1930), Farr (1933), and Ayyar and Ayyangar (1933) let in evidence to show that nuclear divisions on the epidermal cells continued up to the twelfth day and the appearance of cytoplasm in the short hairs denoted that they were of later origin than long hairs. Farr (1933) stated that the later fibres arose from daughter cells derived from the divisions of original epidermal cells subsequent to flowering. Anderson and Kerr (1938) suggested that those produced during the first three days became lint while those formed later became fuzz. Sheffield (1936) noticed stimulation of cell division after pollination and the differentiation of epidermal cells into lint, fuzz and stomata. The division continued for about 10 days. He also found a large initial variability in the

hair initiation between seeds in the same boll and on the same seed, the differentiation being earliest at the chalazal end. The constricted hair base was reported to be due to the base of hair cells increasing rapidly during the first four or five days and getting squeezed by the neighbouring growing cells. Seshadri Ayyangar (1951) contended that three crops of hairs were being produced within a period of 10 days after flowering, primordial hair cells were not present after 10 days, the mesophyll cells bordering deep air cavities divided and multiplied, with one of them protruding through the stomatal pore and growing into a hair after the lapse of 10 days, and such stomatal hairs arose only from fuzzy seeded cottons.

The lint hair is unicellular and its development is phased in two stages: the first is a period of elongation and the second in thickness. A lint cell bulges first, the protoplasm inside turns granular, and the nucleus moves towards the bulge. The swelling enlarges until it is twice the diameter of the original cell and the nucleus moves to or near the tip (Plate XVIII). At this time, the cells have large vacuoles and the walls are still thin. During a period of 24 days, the elongation continues and thereafter ceases. There is no change in thickness. The growth is not regular; slow at first but fast from about the fifteenth day. The rate slackens during days and quickens during nights. The hair initials for lint and fuzz, though similar at first, become very different at maturity. The lint is long while the fuzz remains short.

The cell-wall thickens in the second half of boll maturation. Deposits of cellulose are formed on the inside of primary wall. They are laid in layers as seen from some fibres showing as many as 25 concentric ones. In Egyptian cotton, a mature hair is roughly 2,000 times its diameter. Balls (1919) thought that each concentric layer represented a day's growth and was conditioned by the diurnal variations of temperature. Kerr (1937) found that during secondary wall formation, two lamellae laid down, each 24 hours, constituted the daily growth ring. These two zones differed in porosity, compact zones arising during day and porous ones during night. The porosity variations were traced to temperature changes. Anderson and Moore (1937) proved by experiments that growth rings could be induced by alternating light and darkness and hence concluded temperature alone was not the primary factor. Kerr (1937) used chlorozinc iodide which coloured the primary wall a light blue and the secondary wall a deep violet. He demonstrated that secondary thickening started about the twentieth day and continued for another 30 days or more depending on the environment. The changes in lint characters from fertilisation of flower to dehiscence of boll are illustrated in Fig. 11.

During the first 10 days, the elongating lint is firmly attached to the seed and thereafter it becomes weak until the thirtieth day, regaining some but not all of the firmer attachment at its thickening phase. As soon as the boll dehisces, the hairs dry, collapse, and flatten the cylindrical form, assuming

ribbonlike shape and go into spirals or convolutions. The twisting of fibres causes the lock of seed cotton to expand.

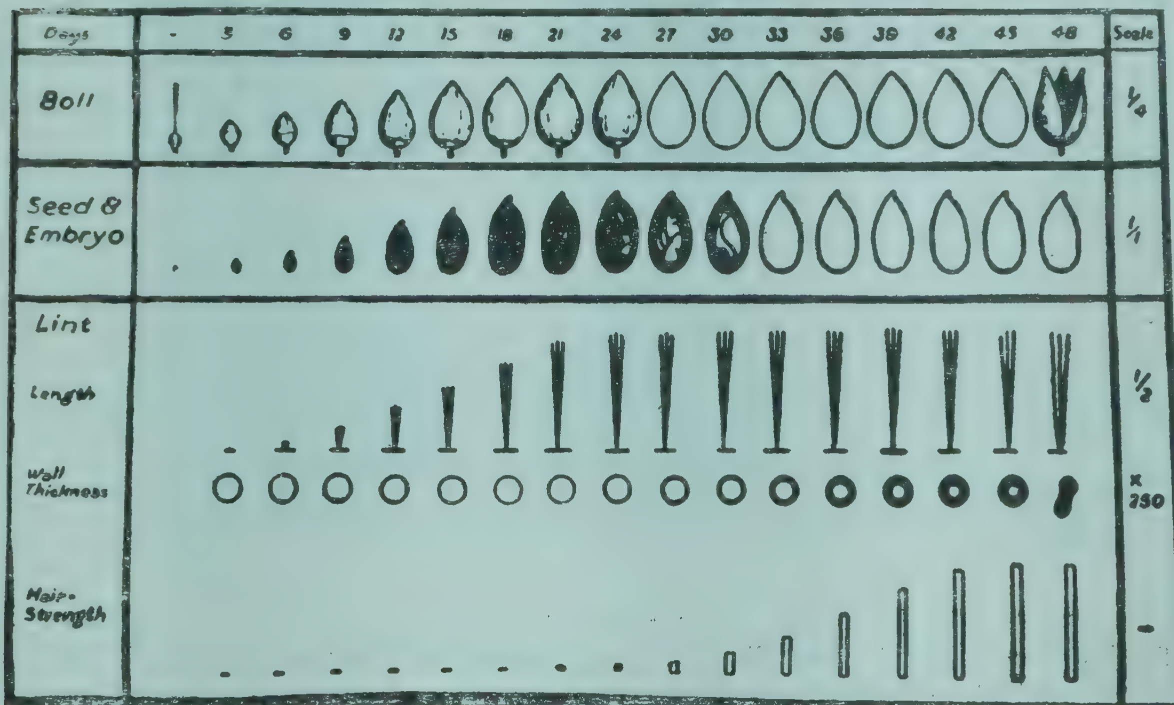


FIG. 11. Diagram drawn to scale, showing the development of Boll, Seed, Embryo and Lint (After Balls).

The mature hair is uniform in diameter up to three quarters its length and then gradually tapers to a point. It is also slightly narrow at the seed end. The size and shape of lumen vary according to the thickness of the wall and determine the degree of flattening in the hair. Recent X-ray analysis showed that the cellulose crystals of cotton fibres were bundles of cellulose chains lying inclined at an angle to the long axis of the fibres. The cotton hair shows on the inside of its wall a 'basket' work the appearance which is the result of a spiral structure. These spirals which constitute the growth rings on the lamina are due to the existence of numerous parallel disconnected fibrils running continuously from the base to the tip of the hair in a spiral manner. The growth rings may be rendered visible by treating the fibres with carbon-di-sulphide and sodium hydroxide or cuprammonium hydroxide. The cell wall swells and the layers are visible under magnifications of over 250.

A sample of lint collected at maturity contains three types: ripe, half ripe and unripe. The ripe fibres have thickened walls and good convolutions ; the unripe fibres, known also as dead fibres, have thin walls, lack twist, and are weak, with a tendency to break up during manufacture ; the half ripe fibres are intermediate between the two (Fig. 12).

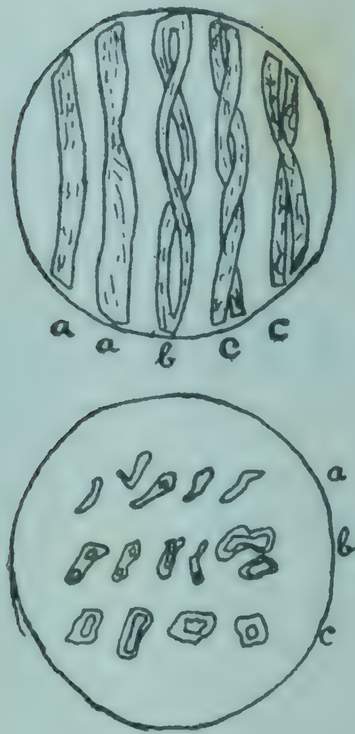


FIG. 12. Cotton fibres in longitudinal view and cross section ; a. unripe fibres ; b. half-ripe fibres ; c. ripe or mature fibres (After Beal).

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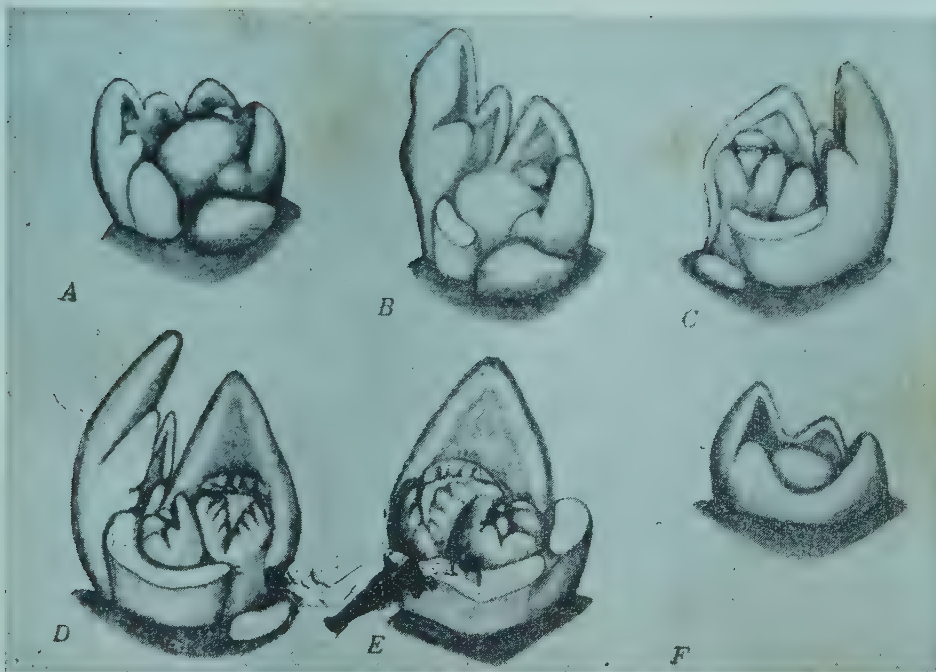
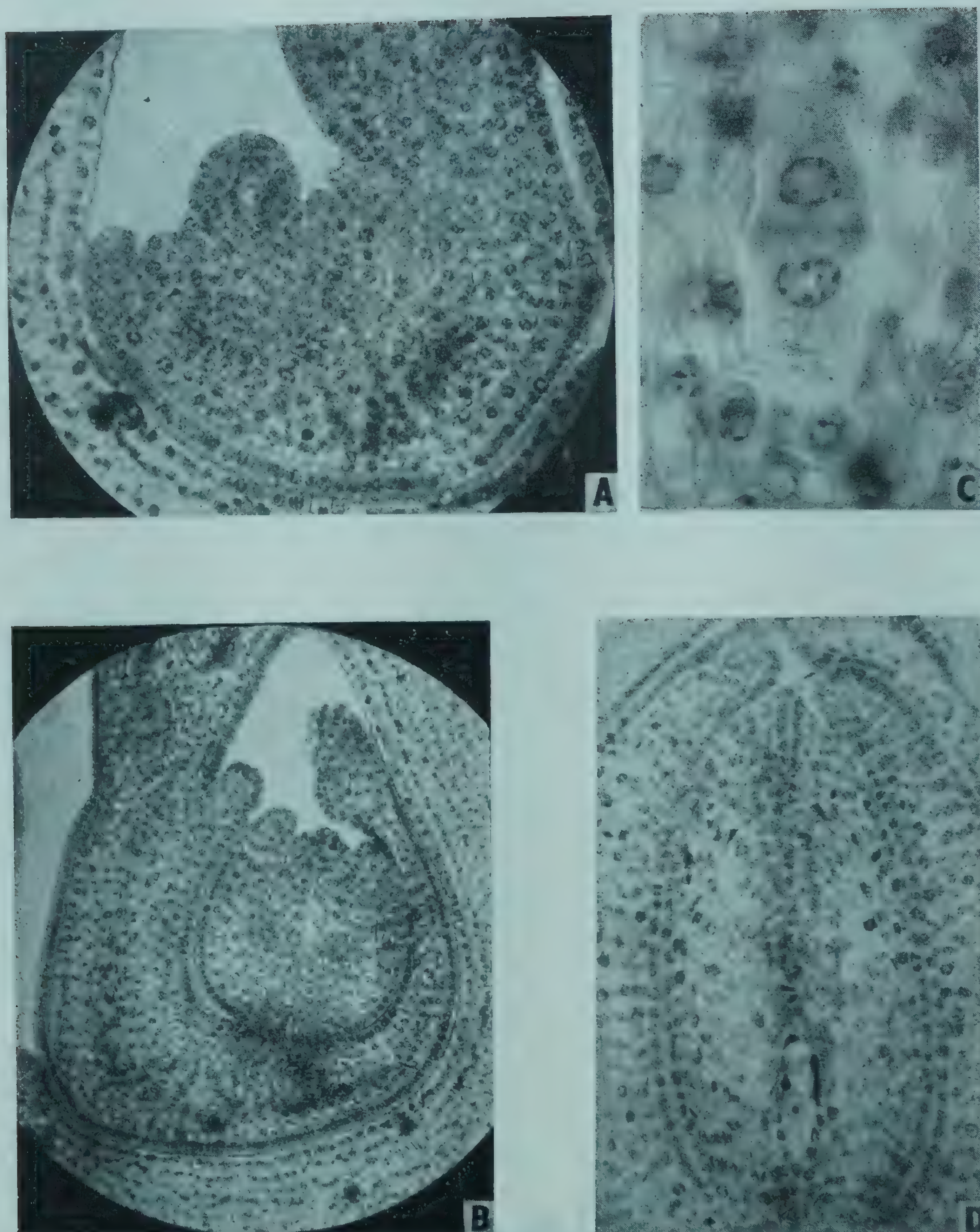


a. A, growing point of cotton stem showing early stages in ontogeny of leaf, stipules, axillary bud, obes of young leaf, and general topography of tip of main axis, drawn from above and slightly to one side, Pima; B, later stage in leaf ontogeny, one stipule cut away, Mebane; C, general topography of fruiting branch terminal, origin of bracts on floral primordium and new axillary primordium, Sea Island; D, later stage in ontogeny of sympodial axis showing slightly older floral bracts, Pima; E, later stage then figure D, showing origin of new fruiting branch terminal between leaf and floral primordium, Mebane; F, axillary bud of fruiting branch showing bractlike structure, growing point, leaf and stipule primordia of second node, Mebane; (After Gore).

b. A, transection of epidermis of ovule on day of flowering showing origin of cotton hairs; B, same, 24 hours after opening showing elongation of hairs. The variety is Mexican Big Boll (After Hayward).



A. *G. hirsutum*, l.s. ovule at megaspore mother cell stage showing origin of integuments.
B. Older stage showing megaspore mother cell in prophase (*After* Romanov, 1954).
C. First meiotic division completed.
D. *G. peruvianum*, functioning megaspore; part of the nucellus is derived by periclinal divisions of the nucellar epidermis (Supplied by Prof. I.D. Romanov).

CHAPTER V

EMBRYOLOGY

INTRODUCTION

A perusal of the available literature reveals that embryological studies on cotton are meagre and far from satisfactory, although considerable work has been done in the fields of cytology, cytogenetics and breeding.

The morphology of the cotton flower has been dealt with by Gore (1935). Doak (1937) has described in detail the structure of the pistil. Hubbard (1930), Sankaran (1931), Ayyar and Sankaran (1934) and Abraham (1935) have reported certain teratological phenomena in flowers. Recently Bhatnagar *et al.* (1959) have described some chemically induced floral variations in Upland cotton. Stomata occurring on floral organs have received the attention of Jivanna Rao (1923), Barritt (1929), Sheffield (1936) and Ayyangar (1948).

Microsporogenesis in a hybrid cotton was studied by Cannon (1903), while Denham (1924) investigated the structure of the pollen grain. Using material of Pima, Sea Island and Upland cottons, Beal (1928) traced the meiotic divisions in the anther and concluded that the heterotypic pairing is parasynaptic rather than telosynaptic as was reported by Denham (1924). Balls (1905), Watt (1907), Badami (1922), Kearney (1923), Kearney and Harrison (1924, 1932), Marsland (1925), Zaitzev (1925a), Banerji (1929b), Shibuya (1930), Trought (1930), Ayyangar (1931), Harrison (1931), Ayyar and Ayyangar (1932), Longley (1933), Doak (1937), Lang (1937), Iyengar (1938), Fulton (1941), Ter-Avanesjan (1944, 1949), Balasubrahmanyan (1948), Johri and Vasil (1955), and Verma and Verma (1957) have contributed to our knowledge on various aspects of cotton pollen.

Balls (1905) described the development of the floral organs, microspore, embryo sac, fertilization, early stages of embryogeny and the development of lint hairs in a variety of Egyptian cotton placed under *Gossypium barbadense.* He reported that the micropylar megaspore functions to form the female gametophyte and that the embryo is devoid of a suspensor. The formation of the female gametophyte and embryo was investigated in three species of *Gossypium* by Gore (1932). Reeves and Beasley (1935) undertook a study of embryogeny from the morphological, physiological and chemical points of view in an American Upland cotton, Startex. Gore (1932) as well as Reeves and Beasley (1935) contradicted many of the findings of Balls (1905). Yamada (1939) has traced the development of the embryo sac, and

fertilization in some varieties of Asiatic and American cottons. Romanov (1954, 1955)* has made detailed contributions on the megasporogenesis and female gametophyte of some species, and Wang and Chien (1957) have studied the development of the endosperm in three strains of *G. hirsutum* by the dissection and whole mount method.

The occurrence of 'motes' in cotton has been a subject of interest to embryologists (Rea, 1928 ; Afzal and Trought, 1934 ; Reeves and Beasley, 1935 ; Afzal, 1937 ; Balasubrahmanyan and Rangaswami, 1948 ; Pearson, 1949 ; Shibuya and Sato, 1951 ; Sato, 1954 ; Weaver, 1957) as have selective fertilization, hybrids and polyploids been to cytologists and cytogeneticists (Zaitzev, 1925b ; Desai, 1927 ; Banerji, 1929a ; Baranov, 1930 ; Harland 1932, 1936, 1955 ; Longley, 1933 ; Webber, 1938 ; Beasley, 1940 ; Silow and Stephens, 1944 ; Weaver, 1958).

Polyembryony (Balasubrahmanyan, 1931 ; Harland, 1932 ; Miège, 1950b), parthenogenesis and parthenocarpy (Balasubrahmanyan, 1931) have been reported as abnormalities. Doak (1937) attempted to induce parthenogenesis artificially in some locules of the ovary while in others he presumed the zygotic embryos to develop normally.

Growth *in vitro* of cotton embryos and a study of the effects of growth substances on them have also been attempted in recent years (Lofland, 1950 ; Dure and Jenson, 1957 ; Mauney, 1958 ; Weaver, 1958).

Among the publications dealing with the structural and other aspects of the cotton seed are those of Harz (1885), Bretfeld (1887), Hanausek (1888), Zwaluwenburg and Schlotterbeck (1889), Winton (1903, 1906), Balls (1915), Barritt (1929, 1932), Singh (1931), Reeves and Valle (1932), Winton and Winton (1932-39) and Reeves (1935, 1936), etc.

A more detailed account is given below.

FLOWER

From the flower primordium arise three bract initials, a sepal zone, a common petal-stamen zone and the carpel primordia.

The calyx is five-sepalled and persistent. The corolla is tubular with five obcordate petals. The staminal column develops from five basic primordia and bears 10 more or less double rows of stamens which number from 90 to 100. The anthers are reniform. Sankaran (1931) has recorded petalody of the androecium in Karunganni cotton (*G. indicum*). The pistil consists of three to five undiverged carpels, a solid style and a globose, glandular stigma whose lobes correspond to the number of carpels.

The ovary, ovules, style, non-hairy portion of the stigma and the anther bear stomata whose guard cells contain starch grains (Jivanna Rao, 1923).

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* We regret that Professor Romanov's papers became available to us only after the MS had already been written. It was nevertheless possible for us to include some of his drawings and photomicrographs (*see* Fig. 14 and Plate XVIII).

MICROSPOROGENESIS AND DEVELOPMENT OF MALE GAMETOPHYTE

Beal (1928) writes: "...the archesporium proper arises from localized areas of the cell layer immediately inside the epidermis, the cells of which divide first by periclinal walls. The outer layer resulting from this division again divides, giving rise to two layers of tissue (vegetative) cells, while the inner layer, in due time, gives rise to the pollen mother cells." Johri and his co-workers (unpublished observations) state that the tapetum is of the glandular type and its cells become binucleate during meiosis.*

The sporogenous cells enlarge and function as microspore mother cells which undergo the usual reduction divisions and give rise to tetrads of microspores.

There are approximately 10,000 pollen grains in a flower (Ter-Avanesjan, 1944). The mature pollen is three-nucleate (Cannon, 1903; Balls, 1905; Denham, 1924; Beal, 1928). The pollen grains of Upland (4n) and Indian (2n) varieties are the smallest, while those of Marie Galante and Pima (4n) are the largest. There is no clear correlation, however, between chromosome number and pollen grain size (Marsland, 1925).

Watt (1907) has classified cotton pollen into four chief types based on the nature of the exine and the spines present on it. He adds, however, that more than one type of grain may occur in the same flower (*see also* Ter-Avanesjan, 1944).

Lang (1937), working with *G. punctatum*, has shown that the pollen grains contain numerous tiny spherical starch granules. The exine shows as many as 24 germ pores but there is no definite correlation between the diameter of the grain and the number of pores (Trought, 1930).

In some varieties pollen grains begin to germinate as soon as they reach the stigma, if conditions of temperature and humidity are favourable. Several tubes may emerge from a single pollen grain (Iyengar, 1938). Sixtyeight per cent. of the grains showed the formation of double tubes in the tetraploid species, *G. hirsutum* ; whereas in the diploid species, *G. herbaceum*, the number was only 25 per cent. Desai (1927) reported that 24 hour old pollen failed to effect fertilization. Banerji (1929b) adduces experimental evidence to show that under natural conditions a fairly high percentage of pollen grains is viable up to the twentyfourth hour after liberation from the anther but loses potency within the next 24 hours. Balasubrahmanyan (1948) has found pollen from immature flower buds (due to open a couple of days hence) to withstand a 44 hour journey after removal from the parent plant. He states that pollen from still younger buds may remain viable and stand transport for still longer periods. Banerji (1929b) noticed the germination of pollen inside the flower itself when atmospheric conditions were congenial.

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* We are indebted to Dr. B. M. Johri for permitting us to include here some of his unpublished observations on the embryology of cotton made under a research scheme financed by the Indian Central Cotton Committee.

As a medium for artificial germination of cotton pollen, Badami (1922) tried cold-drawn castor oil. Banerji (1929b) found that the chief requirement for the successful germination of cotton pollen is careful control of moisture and on this ground he doubted Badami's claim of pollen germination in castor oil. Shibuya (1930) and Longley (1933) arrived at a similar conclusion. Iyengar (1938) germinated the pollen grains in an agar-sugar medium (Fig. 13 A). Johri and Vasil (1955) obtained good germination of pollen of *G. herbaceum* by adding boric acid to the medium. Recently Verma and Verma (1957) reported absence of germination in a sucrose solution.

The wall of the pollen tube shows characteristic lamellae (Fig. 13 D). Normally the tip shows only a slight swelling (Fig. 13 C) but this is much larger

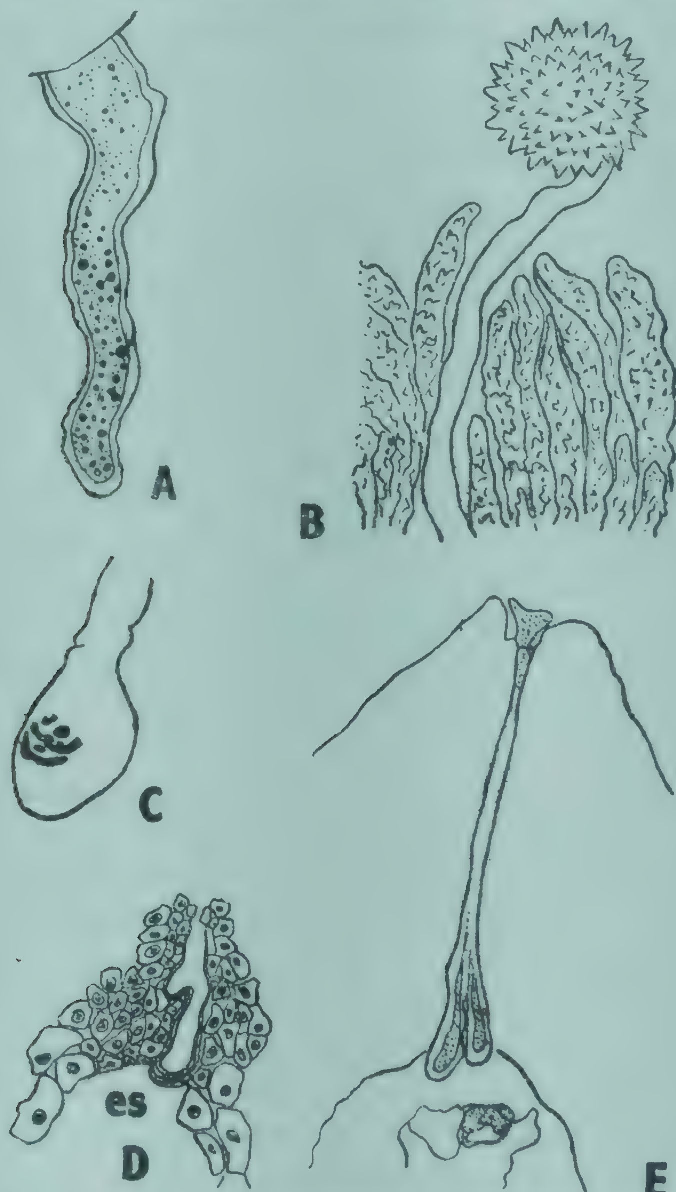

FIG. 13. A. Pollen germination in artificial medium. Note migration of food reserves to tip of tube. x 1080. B. Pollen tube growing between the papillate cells. x 165. C. Dilated end of pollen tube showing degenerating nuclei. x 562. D. Pollen tube entering the embryo sac (*es*). Note lamellate wall and short process. x 165. E. Same, branching near wall of embryo sac. x 165. (*After* Iyengar, 1938).

in slow growing tubes. A tendency towards branching is not so pronounced in rapidly growing tubes as in the slow growing ones. The diameter varies, the polyploid species having larger pollen grains and tubes (Iyengar, 1938).

The pollen tubes, after passing between the papillate cells of the stigma (Fig. 13 B), bend down sharply into the soft transmitting tissues of the style and ovary. According to Doak (1937), the course of pollen tubes is predetermined since each stigmatic lobe is directly in line with its corresponding locule and the ovules therein, and a direct connection is established between them through the conducting strand and the nutritive placental ridge. However, an intercarpellary switch-over of pollen tubes is not precluded.

The time taken by the pollen tube to traverse the style varies according to the variety and the environmental conditions. Zaitzev (1925a; quoted by Banerji, 1929b) recorded a 10 hour journey down the entire style. Kearney and Harrison (1924) noted a 10-12 hour period in Pima cotton. Banerji (1929b) obtained similar results in *G. herbaceum*. Iyengar (1938) reported a duration of 13 hours. Balls (1905) stated that in Egyptian cotton the pollen tubes were seen in the embryo sac 30 hours after pollination.

The pollen tubes become coiled in various ways during their growth in the pistil. Such coiled tubes are abundant when pollen of American cottons (4n) is placed on the stigma of Indian forms (2n). Alien pollen tubes (tubes of a different species or variety) grow more slowly than own pollen tubes, and the more genetically distant the forms are, the greater is the retardation. Callose plugs shut off the advancing tip from the older portions and the first plug is laid between 160 to 300 microns from the grain (Iyengar, 1938).

The pollen tubes grow through the placenta, travel up the funiculus, and finally reach the micropyle. They often cross from one placenta to the other (Ayyangar, 1931; Iyengar, 1938).

In the micropyle the pollen tube follows either a straight or a zigzag path depending upon the alignment of the exostome and the endostome, sometimes growing for a short distance between the two integuments, or the inner integument and the nucellus and forking at the tip (Fig. 13 E). Two to four layers of nucellar tissue are digested during its passage to the embryo sac.

The order of the entry of pollen tubes into the ovules does not seem to depend upon the position of the latter in the locule (Ayyar and Ayyangar, 1932; Iyengar, 1938). However, in a variety of *G. hirsutum* the first tubes seemed mainly to enter the ovules of the third position and the frequencies were less in all the ovules in the even position (Ayyar and Ayyangar, 1932).

More than one tube may enter an ovule. While examining ovules from withered flowers, Ayyangar (1931) noticed two pollen tubes at the micropyle but the frequency of such an occurrence or the fate of the extra tubes is not mentioned. Iyengar (1938) reported that about 24 per cent. of the ovules examined by him showed as many as four tubes at various distances down

the micropyle. He could not determine their behaviour but mentions that no evidence of polyspermy could be obtained either with reference to the embryo or the endosperm.

Harrison (1931) and Fulton (1941) have observed metaxenia in Acala, Hopi and Pima cottons. They found the pollen to influence the staple length and other boll characters.

OVULE

The placental epidermis is glandular. Starch, oil and calcium oxalate crystals are present in the cells of the axile placenta. The ovary contains up to 40 ovules (Ter-Avanesjan, 1944). They become completely anatropous by the time the megaspore mother cell is in the prophase (Plate XVIII B). The funiculus is long and massive. Like the placenta, this too is covered by a glandular layer which probably serves a nutritive role in the growth of the pollen tubes.

The nucellus is well developed and there are two integuments (Plate XVIII A, B) of which the inner is partially resorbed before the seed matures. Gore (1932) writes: "The outer integument appears first, or about the time the inner integument appears, both growing over and around and practically covering the nucellus by the time of the first division of the megaspore mother cell. The outer integument grows somewhat faster than the inner integument and at the time tetrads are visible, surrounds the nucellus. The inner integument does not cover the nucellus at this stage. However, this is quite variable in the different species." At the time of opening of the flower the inner integument consists of 10-12 layers of cells and the outer of 6-8 layers (Gore, 1932). According to Barritt (1929) vascular bundles are present in both the integuments but this needs confirmation. The outermost layer of the outer integument is of special significance since it gives rise to the lint.

Jivanna Rao (1923), Barritt (1929) and Sheffield (1936) reported the occurrence of stomata on cotton ovules. Ayyangar (1948) made a thorough study of the formation, development and distribution of the stomata in the ovules of a number of varieties of Asiatic and American cottons. They are seen at the chalazal end two days prior to the opening of the flower and are recognizable over the entire surface of the ovule after the third day. Stomata continue to be formed up to the twentyfourth day after anthesis. According to Ayyangar (1948) their chief role is in respiration.

Sterile, abnormal and abortive ovules ('motes') occur occasionally (Rea, 1928 ; Afzal and Trought, 1934 ; Reeves and Beasley, 1935 ; Afzal, 1937 ; Pearson, 1949 ; Shibuya and Sato, 1951 ; Sato, 1954 ; Weaver, 1957). Rea (1928) obtained some evidence that this is due to lack of fertilization. On the other hand, Afzal and Trought (1934) considered nutritional defects of individual bolls as responsible for the occurrence of motes. Balasubrah-

manyan and Rangaswami (1948) are of the opinion that contabescense of anthers might increase the percentage of motes through a reduced supply of functional pollen. In an investigation of the embryology of a triploid hybrid between *G. hirsutum* x *G. arboreum*, Weaver (1957) has traced mote formation to an antagonism between the hybrid embryo and endosperm. According to him the hybrid embryo exerts a deranging effect on the endosperm which would otherwise develop normally. Such embryo-endosperm antagonism was, however, not noticed in the reciprocal cross (Weaver, 1958).

Shibuya and Sato (1951) and Sato (1954) have classified motes into three types : (*i*) ovules without embryo sac formation ; (*ii*) normal but unfertilized ovules ; and (*iii*) fertilized ovules whose later development is arrested. Thus, they distinguish fertilized and unfertilized motes. The latter may result from the absence of an embryo sac. Or, even if the embryo sac is present the egg, synergids and polar nuclei are either displaced or imperfectly organized, or the ovule may be shrunken. Usually it is the shrunken ovules which lead to mote formation. These are located in a definite pattern in the lock, the middle or top having the smallest number. In Upland cotton, mote production decreases from the bottom to the top of the lock, while the reverse condition occurs in Chinese cotton (Shibuya and Sato, 1951).

In a cross between *G. herbaceum* (Strain 405) and *G. neglectum* (*cernuum*), extracarpellary, naked ovules sometimes arise directly from the floral axis above the level of the carpels (Abraham, 1935). Such ovules appeared to represent the continuation and termination of the floral axis. They were fully developed and were even fertilized like normal ovules. Yamada (1939) has reported extraplacental but intracarpellary ovules. However, they were not typically anatropous but showed a normal gametophyte.

MEGASPOROGENESIS AND FEMALE GAMETOPHYTE

The archesporium is sub-epidermal and originates before the differentiation of the integuments (Fig. 14 A). A parietal cell is cut off and forms a massive tissue by repeated divisions (Fig. 14 A; Plate XVIII D). More than one megaspore mother cell may occur sometimes and form dyads and tetrads (Fig. 14 B-G; Plate XVIII C). Romanov (1954, 1955) has reported the occurrence of linear, T-shaped and isobilateral tetrads (Fig. 14 F-H, L) and also some intermediate types and variations (Fig. 14 I-K).

Generally the three micropylar megaspores perish at a very early stage (Plate XVIII B). Balls' (1905) report that the micropylar megaspore functions seems to be incorrect. In all the three species studied, Gore (1932) and Yamada (1939) found that the chalazal megaspore functions. Johri and his co-workers (unpublished observations) confirm this in *G. arboreum* and *G. herbaceum*.

The nucleus of the functioning megaspore undergoes three successive divisions resulting in an eight-nucleate embryo sac which is organized nor-

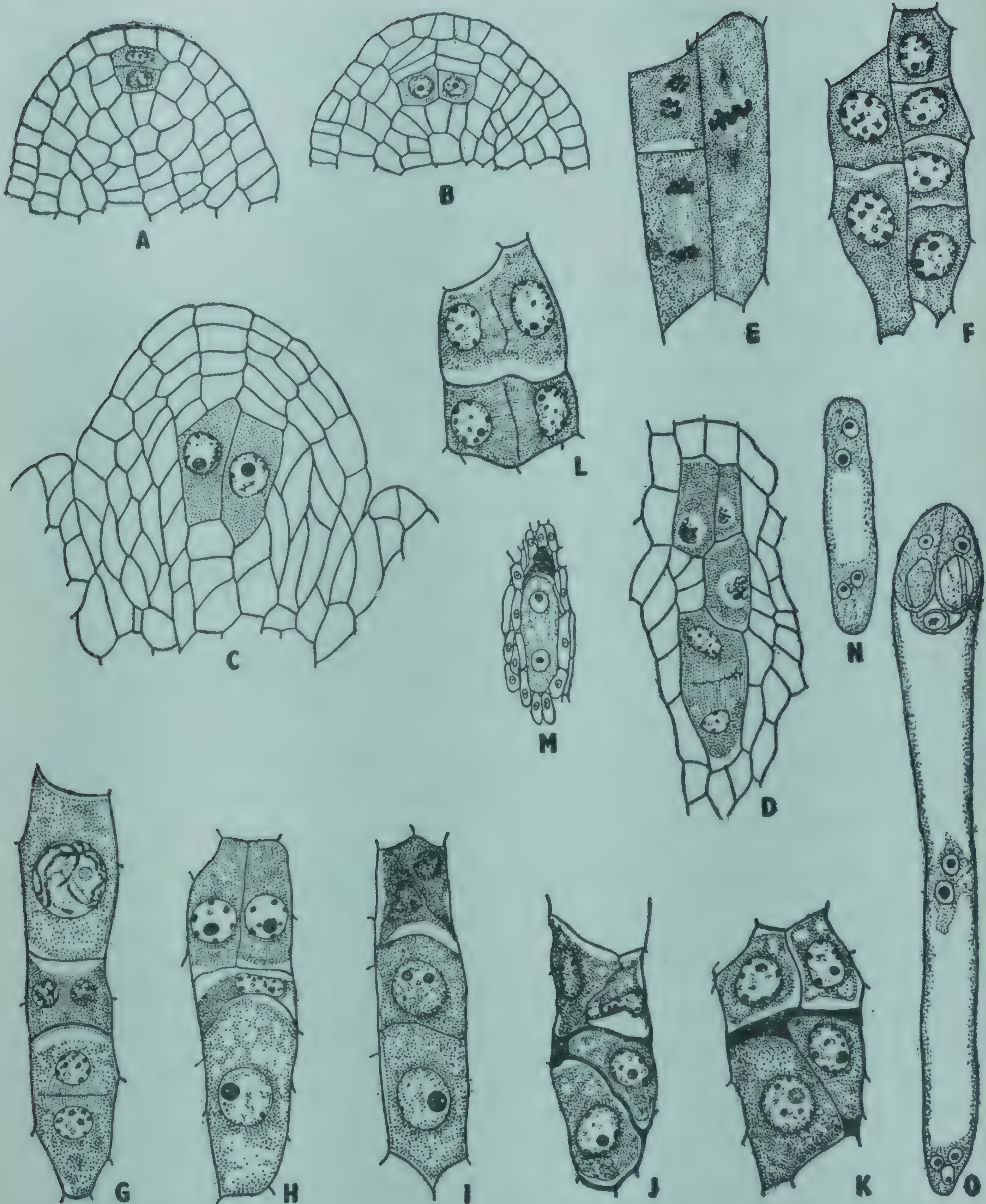

Fig. 14. A. *G. herbaceum*, l. s. nucellus showing primary parietal and sporogenous cells. B. Two megaspore mother cells. C. *G. barbadense*, enlarging megaspore mother cells; some cells of the nucellar epidermis have also undergone periclinal divisions. D. *G. herbaceum*, four megaspore mother cells; upper three in prophase and the lower in telophase. E. Two megaspore mother cells of which the one on the left is in second meiotic division. F. *G. arboreum*, dyad and linear tetrad. G. Dyads in division to form a T-shaped tetrad; the uppermost cell is a megaspore mother cell in prophase. H. T-shaped tetrad. I. *G. barbadense;* J, K. *G. herbaceum*, variations in tetrad formation. L. *G. herbaceum*, isobilateral tetrad. M, N. *G. hirsutum*, two and four-nucleate embryo sacs. O. *G. peruvianum*, eight-nucleate embryo sac. (*A-D after* Romanov, 1954; *E-L after* Romanov, 1955; *M-O after* Gore, 1932).

mally (Fig. 14 M-O). The egg is pear-shaped and its nucleus is imbedded in a scanty mass of cytoplasm at the terminal end. The synergids are pyriform and vacuolate at the lower end. They possess the usual filiform apparatus. The polar nuclei lie very close to each other in a jagged mass of cytoplasm. The antipodals are ephemeral and the mature embryo sac is only five-nucleate at the time of anthesis.*

Many layers of nucellar cells surround the embryo sac at its micropylar end and on the sides (Plate XVIII D). The cells at the chalaza and on the sides contain large quantities of starch and probably supply nutrition to the embryo sac and the embryo. Just below the starchy cells at the chalazal end there are several thick-walled cells to which Gore (1932) attributes a conducting function. According to Hanausek (1888; quoted by Reeves and Valle, 1932) the starchy cells develop into a thick, loose, pigmented tissue which he designated as the "Chalazagewebepolster."

In *G. herbaceum*, Baranov (1930) reported the frequent occurrence of more than one embryo sac and this has been confirmed by Gore (1932) in Delfos cotton. Regarding the origin of the supernumerary embryo sacs, Gore makes contradictory statements and since there are no illustrations positive conclusions cannot be drawn. He writes : "In these cases no doubt two megaspore mother cells were present and each developed, though in the enormous number of ovules of all varieties examined only one mother cell has ever been found in an ovule. It is possible that more than one megaspore of the tetrad functioned."

FERTILIZATION

The interval between pollination and fertilization varies from 36 to 40 hours (Balls, 1905). In Egyptian cotton, Balls noticed pollen tubes and zygotes on the afternoon of the second day after pollination. Kearney (1923) found that in Pima cotton fertilization, and fruit and seed setting were not prevented by excising the style 10-12 hours after pollination. Gore (1932) recorded that in Delfos cotton the interval between anthesis and the entrance of the pollen tube was approximately 15 hours. Fertilization was accomplished within 24-36 hours after pollination (Yamada, 1939).

Kearney (1923), Kearney and Harrison (1924), and Zaitzev (1925b) have reported selective fertilization in favour of like pollen when unlike although compatible pollen is also present. Ter-Avanesjan (1949) states that pollination with a limited number of pollen grains leads to a more pronounced selective effect.

According to Gore (1932) the pollen tube enters through one of the synergids whose remnants persist for a considerable time. However, Gore's illustrations are not clear in this respect and his observations need corroboration.

* According to Johri and his co-workers (unpublished data) *G. arboreum* and *G. herbaceum* sometimes show 5-8 antipodal cells.

Yamada (1939) reports that with the entrance of the pollen tube, usually one synergid is destroyed. The other synergid as well as the pollen tube persists for sometime after fertilization (Iyengar, 1938; Yamada, 1939).

ENDOSPERM

The polar nuclei may fuse either before or simultaneously with the entry of the male gametes. In Pima cotton division may set in before the fusion is complete (Gore, 1932). The resulting nuclei move to the poles of the embryo sac and divide repeatedly. In five day old endosperm, the number of free nuclei is a little over 1,000. Islets of free nuclei show mitotic activity and a gradation is seen along the long axis of the embryo sac. The size differences in the nuclei particularly those at the chalazal end are due to occasional irregularities like amitosis and nuclear fusion (Wang and Chien, 1957). Wall formation sets in when the embryo has 20-25 cells and takes place by furrowing. The first formed endosperm cells are uni or multi-nucleate but later all the cells become uninucleate.

Only one or rarely two layers of endosperm persist, while the rest is consumed. Like the embryo, the six day old endorsperm is rich in carbohydrates and proteins (Reeves and Beasley, 1935).

When mature seeds are stored, the embryo often shrinks and becomes very loose in the hull ; the so-called perisperm and endosperm separate from the hull but remain attached to the embryo (Reeves and Valle, 1932).

In *G. arboreum* x *G. hirsutum* hybrids, about four days after pollination, the endosperm begins degenerating and by the fourteenth day it is completely destroyed. No wall formation takes place but several abnormalities like dumbbell-shaped and clumped nuclei have been seen (Weaver, 1958).

EMBRYO

Accounts of embryogeny are rather sketchy. Many stages of development have only been assumed. Opinions differ even as to the presence or absence of a suspensor.

On the second day after fertilization, the zygote divides transversely (Fig. 15 A) to form two unequal cells of which the one nearest the micropyle is designated as the 'suspensor cell' (Gore, 1932).

The first division is followed by a vertical or sometimes a diagonal division in *ca* (Fig. 15 B, C). The cell *cb* also may divide vertically, or may remain undivided to form a one-celled suspensor (Fig. 15 B, D, E). Three-celled proembryos are most frequent on the second day after fertilization.

The quadrant stage has not been figured but according to Reeves and Beasley (1935) "a perfect quadrant is probably formed and various slight departures from it are common." Octants are formed on the fourth day after fertilization and the differentiation of a dermatogen sets in the same day (Fig. 15 F-K).

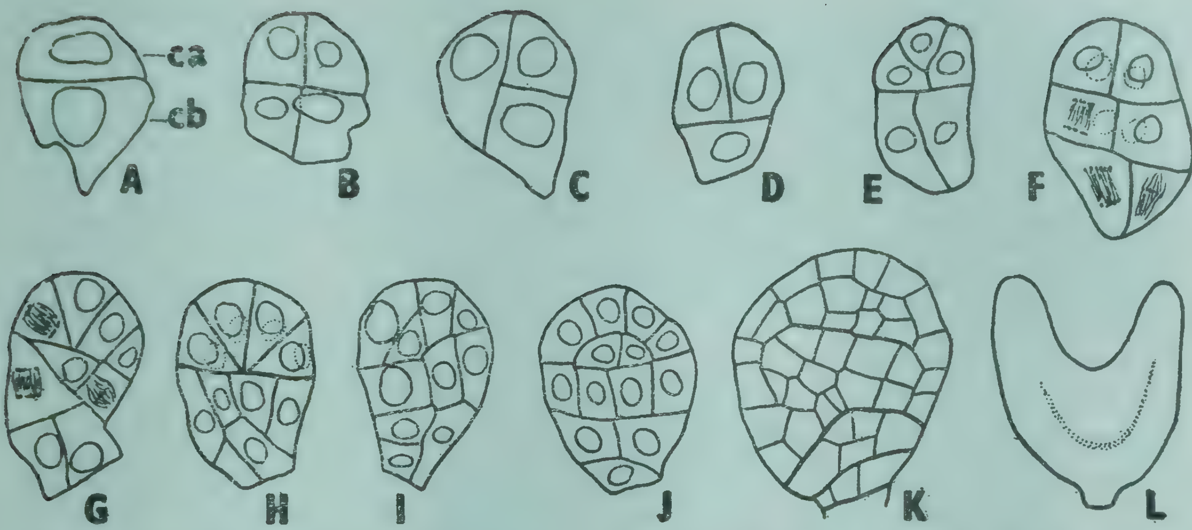

FIG. 15. Stages in development of embryo. A. 2-celled embryo. x 366. B. 4-celled embryo. x 366. C-E. Variations in sequence of divisions in *ca* and *cb*. x 366. F. Octant. x 366. G-K. Globular embryos. x 366. L. Heart-shaped embryo. x 82. (*After* Reeves and Beasley, 1935).

When the embryo is eight to ten-celled, the suspensor is only three-celled. Even in older embryos the suspensor remains quite small (Gore, 1932). Reeves and Beasley (1935) report that it sometimes disorganises which explains Balls' (1905) statement that the cotton embryo has no suspensor. Gore (1932), on the other hand, offers a different explanation. According to him Balls' drawing of the octant stage of the embryo was probably made from a cross-section which naturally would not show the suspensor.

Between the sixth and the ninth day, the embryo becomes heart-shaped and shows the dermatogen, periblem, and plerome (Fig. 15 L). The two lobes of the heart-shaped embryo develop into the cotyledons, and soon after the plumule makes its appearance as a mound of tissue between them. A fortnight after fertilization the plumule is quite conspicuous and the mesophyll in the cotyledons consists of one or two layers of slender palisade cells and several layers of spongy parenchyma ; resin ducts appear in the spongy mass. When the embryo is 18 day old, all the organs and provascular tissues are well developed and later there is merely an increase in its size. Numerous irregularities of form are observed in mature embryos (Reeves and Beasley, 1935) and the folding of the cotyledons is variable. Miège (1950a) has recorded tricotyledony. Essentially the embryogeny resembles that of *Malva rotundifolia* described by Souèges (1922).

Harland (1932 ; quoted by Webber, 1938) reported the sporadic occurrence of polyembryony in several strains of cultivated American cottons. The polyembryonic seeds gave rise to twin plants both of which were either identical diploids or one was diploid and the other a haploid. He found that all the haploids were male sterile but some strains of Sea Island cotton were partially female fertile. If, as seems probable, polyembryony in cotton involves the production of more than one embryo sac, an opportunity is

thereby provided for the development of an embryo from an unfertilized egg alongside its fertilized neighbour.

Webber (1938) was successful in raising : (*i*) two diploid twins of Acala cotton (*G. hirsutum*) ; (*ii*) conjoined diploid twins of *G. nanking* x *G. thurberi* F_2 ; and (*iii*) haploid-diploid twins of *G. barbadense*. He concluded that the occurrence of twins in *G. nanking* x *G. thurberi* F_2, was probably due to sporophytic budding or diploid parthenogenesis.

Twinning in the Sea Island cottons is more frequent than in the other types of cultivated cotton. In the Sea Islands, most twin pairs are diploid-haploid, and the few cases of diploid-diploid twins probably started off as diploid-haploid. In the Asiatic cottons twins are predominantly of the diploid-diploid type and both members are probably the result of fertilization. The mode of origin of the diploid-diploid twins is not clear. There is no evidence as to whether, like diploid-haploid pairs, they also arise from two embryo sacs, and if so whether both of them are fertilized, or only one, the other embryo then resulting from the doubling of the chromosome number in a parthenogenetic haploid egg. Additional possibilities are sporophytic budding ; or, in the special case of identical twins, the cleavage of a single zygote (Silow and Stephens, 1944).

The occurrence of haploids in allopolyploid cottons is usually, though not always, associated with polyembryony. Very rarely haploids may also occur in monoembryonic seeds in Okra, Peruvian, Pima, Sea Island and Tanguis cottons and in *G. hirsutum* x *G. barbadense* hybrids (Harland, 1936, 1955).

During recent years cotton embryos have also attracted the attention of physiologists. Lofland (1950) cultured embryos of the Upland cotton, *G. hirsutum*, at three stages of development : (*i*) 15-16 day old, flat, 3-4 mm. embryos ; (*ii*) 20-21 day old, immature, 7-8 mm. late torpedoes ; and (*iii*) 27 day old mature embryos. Normal seedlings were obtained only in the third case. Those of the second category showed slow growth and many abnormalities, while 15 day old embryos failed to grow. Lofland found that the use of malt and cotton extracts, coconut milk and sodium nucleate as supplements had no beneficial effect in his cultures.

Dure and Jensen (1957) selected embryos of *G. hirsutum* weighing 37 and 64 mg. fresh weight. Rapid cell division and elongation were brought about by gibberellic acid 10^{-5} M in embryos of 64 mg. fresh weight.

Mauney (1958) has been able to culture heart-shaped embryos to maturity in White's medium (mineral salts raised to five times the original level) supplemented by adenine, casein hydrolysate and coconut milk. Gibberellic acid, IAA and kinetin were detrimental to normal embryonic growth.

Hybrid embryos of *G. arboreum* x *G. hirsutum* ranging from 20 days after pollination to maturity, cultured on White's medium, showed varying degrees of growth, but only one developed into a normal seedling (Weaver, 1958). Better growth was obtained in cultures of embryos excised one month after

pollination. According to Weaver, the abnormal behaviour, like callusing, formation of roots only, or of deformed cotyledons, and failure to produce normal seedlings are due to incomplete differentiation of the cultured embryos.

SEED COAT

The exact development of the seed coat has not been traced satisfactorily, but at maturity it consists of six layers (Reeves, 1936): (*i*) epidermis; (*ii*) outer pigment layer; (*iii*) colourless layer; (*iv*) palisade layer; (*v*) inner pigment layer; and (*vi*) fringe layer (Fig. 16).

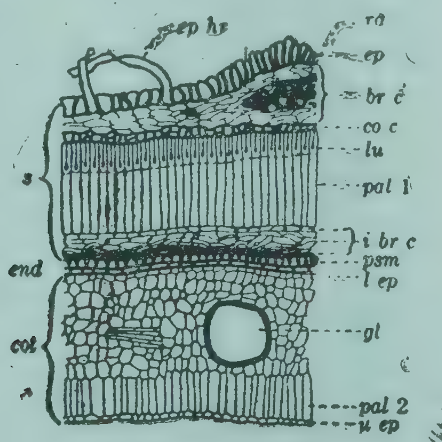

FIG. 16. Section through seed. *br c*, outer brown coat; *co c*, layer of colorless cells; *cot*, cotyledon; *end*, endosperm; *ep*, epidermis; *ep hr*, epidermal hair; *gl*, gland; *i br c*, layers of inner brown coat; *l ep*, lower epidermis of cotyledon; *lu*, lumen of palisade layer of seed coat; *pal* 1, palisade cells of seed coat; *pal* 2, palisade cells of cotyledon; *psm*, perisperm consisting of fringe cells; *ra*, raphe; *s*, seed coat; *u ep*, upper epidermis of cotyledon. (*After* Winton and Winton, 1932-39).

The epidermis has received a considerable amount of attention since it gives rise to the hairs (Fig. 17 A-C) which form the cotton of commerce. It is composed of large, irregular cells which vary in size and form rosettes around the hairs. In surface view the cells are somewhat stratified, the thick cellulose walls are yellow, and the lumina are small and contain minute quantities of brown protoplasmic remains. Single or paired stomata with a well developed circular orifice formed by the guard cells are found depressed below the surface.

The outer pigment layer consists of thin-walled cells containing a brown pigment and is greatly thickened in the region of the raphe. Reeves and Valle (1932) are of the opinion that these cells nurse the lint hairs until shortly before the seed is mature.

The colourless zone, designated as the crystal layer by some authors, lies external to the palisade layer. It is one to three-layered, the cells are approximately isodiametric, lignified and appear four-sided in sections.

The palisade layer, also called the Malpighian layer, is one cell thick. The cells are greatly elongated and highly lignified leaving no lumen (Fig. 17 D). The cell walls possess various markings running both lengthwise and crosswise (Fig. 17 D-F, H). The latter are seen at about one-third the length of the

cell from the outer end and indicate a region of mechanical weakness. Toward the outer end from this region is found a small mass of brown pigment (Fig. 17 G) similar to that in the inner pigment layer. Barritt (1929) states that the palisade cells fit very closely together from the inner end up to about two-third of their length, at which point the cell walls bend inward forming a 'shoulder' and leaving intercellular spaces. These are continuous with those of mesophyll and the cavity below the stomata. This bottle-neck shape of the outer portion of a palisade cell is visible only in thin sections. Singh (1931), on the contrary, states that the palisade cells are shaped like an hour glass or

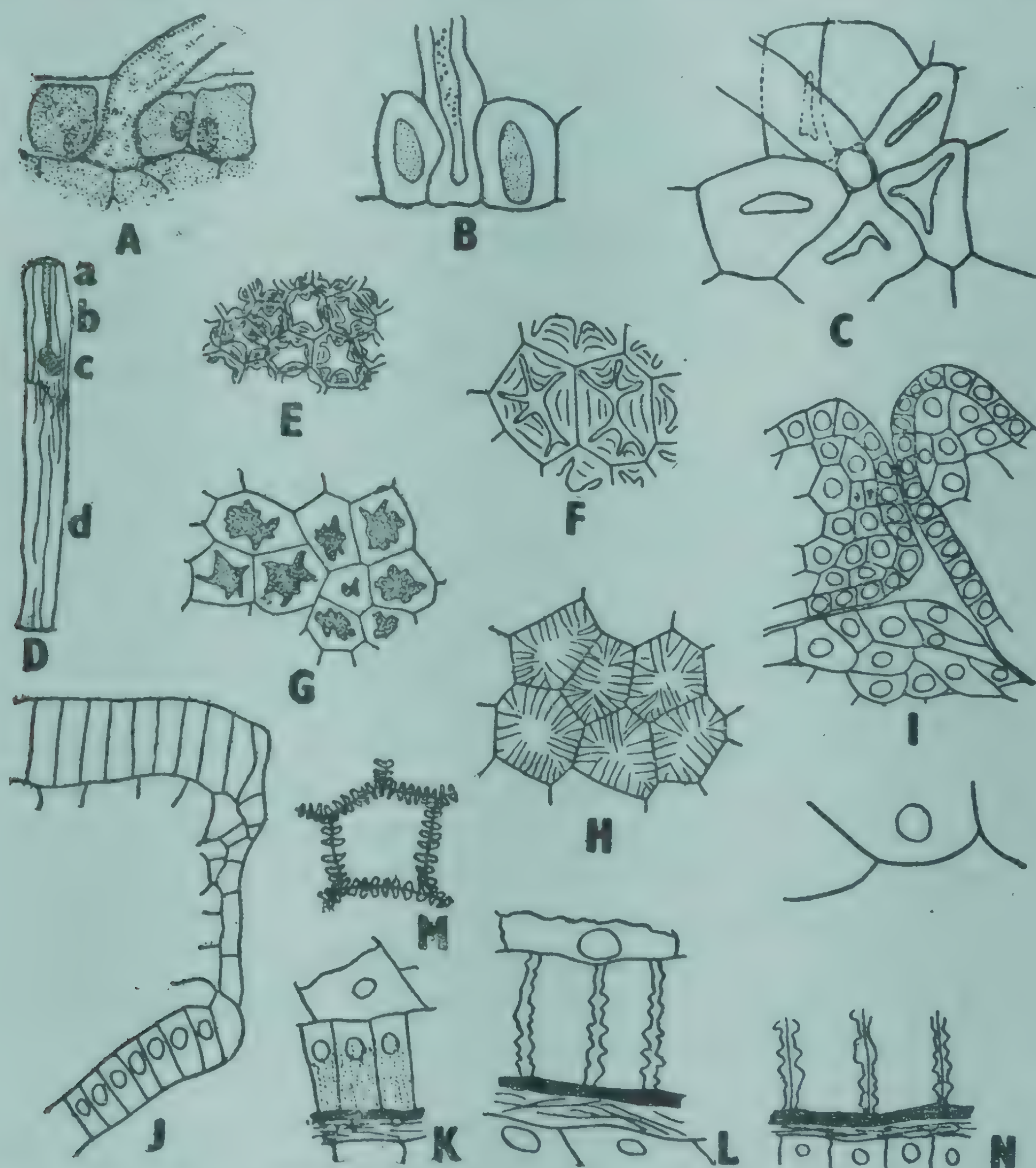

FIG. 17. A. Section through epidermis showing young lint hair. x 311. B. Same, showing mature hair. x 232. C. Surface view of mature hair. x 232. D. L.s. palisade cell. x 232. E-H. Transections at regions *a-d* in Fig. D. E. x 232, F-H. x 450. I. Section through endostome of young ovule showing epidermises of the two integuments. x 450. J. Section of slightly older inner integument at endostome showing beginning of differentiation of both epidermises. x 450. K, L. L.s. young and mature fringe cells. x 650. M. Mature fringe cell showing the markings. x 650. N. L.s. fringe tissue getting separated from the inner integument. x 650. (*A-H, After* Reeves and Valle, 1932; *I-N, After* Reeves, 1935).

a tumbler as seen in longitudinal section. Reeves and Valle (1932) also failed to find any shoulder and consider Barritt's (1929) report to be incorrect.

The palisade layer, according to Barritt (1929), is the inner epidermis of the outer integument, and the two integuments show typical leaf structure: epidermis, palisade and mesophyll, containing vascular tissue. The inner palisade tissue disorganises after the second week, and remains as a mere parchment-like membrane in the mature seed. The palisade tissue of the outer integument continues to elongate radially, from the twelfth to the twenty-fourth day, until it is about 12 diameters in length. Singh (1931) reports only the outer palisade layer, while Reeves and Valle (1932) state that the inner palisade layer becomes resorbed. Reeves (1936) considers that the palisade layer originates from the outer epidermis of the inner integument.

The inner pigment layer varies in thickness and resembles the outer in structure and development. Balls (1915) stated that the fragmentary remains of the inner integument form the second pigment layer.

The mature embryo is enclosed by a white sheath whose nature has been much debated. Hanausek (1888) considered it to consist of two tissues, the outer of which he designated as 'Franzenzellen' (fringe cells). He agreed with Harz (1885) that this represents the perisperm, while the inner portion of the sheath belongs to the endosperm. Bretfeld (1887) described the outer portion as '*dem Knospenkern hervorgegangenen Schichte*'. In discussing the membrane which separates the inner pigment layer from the embryo, Zwaluwenburg and Schlotterbeck (1889) remarked that "it is composed of the obliterated nucellus and endosperm and the inner epidermis of the inner integument." Winton (1906) called the sheath a perisperm, indicating that it is the remnant of the nucellar tissue. Reeves and Valle (1932) also accepted it as a true perisperm. But later Reeves (1935) found that the term perisperm, as applied to the cotton seed, is a misnomer since the tissue in question originates from the inner epidermis of the inner integument (Fig. 17 I, J). He approved the term 'Franzenzellen' used by Hanausek (1888) and translated into English as 'fringe cells' by Winton (1903).

When mature, the fringe cells are devoid of contents (Fig. 17 L-N). Their radial and transverse walls contain lignin and suberin and are very irregular showing many tooth-like projections which extend into the lumina (Fig. 17 K, M).

The peculiar markings on the mature fringe cells are described as nodular and wavy (Bretfeld, 1887). According to Hanausek (1888) the fringe cells are polyhedric with highly ramified and particulated walls. Zwaluwenburg and Schlotterbeck (1889) noticed wavy and indistinct outlines due to irregular thickenings.

The fringe tissue is thicker near the micropyle owing to a greater elongation of the cells in this region and is never found attached to the inner integu-

ment. It becomes disconnected because of the resorption of the parenchymatous cells of the inner integument (Fig. 17 N) and was, therefore, mistaken as the remnant of nucellar tissue.

Of the nucellus, only the cuticle and a few fragments remain at maturity (Reeves, 1935). As the seed matures and at the time of cracking of the boll, the colour changes from white to grey.

To conclude, the embryology of cotton is still only imperfectly known. A thorough and critical reinvestigation of the life-history of the Asiatic as well as the New World cottons is essential.

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CHAPTER VI

BREEDING

The genus *Gossypium* comprises 20 wild and cultivated species which are grouped into eight sections by Hutchinson, Silow and Stephens (1947). According to them all the cultivated cottons fall under four species only. Of these, the two Old World species, *G. arboreum* L. and *G. herbaceum* L., are diploid ($n=13$) and the two New World species, *G. hirsutum* L. and *G. barbadense* L., are allotetraploid ($n=26$).

India has been recognised as the ancient home of *G. arboreum* which forms the bulk of the cotton crop grown in the country even today. The studies of Gulati and Turner (1928) have shown that in measurable characters the *Mohen-jo-daro* cotton resembled the modern cottons of the northern group of *G. arboreum*. Hutchinson (1954) is of the view that the ancient Indus Valley Civilisation played an important part in the development and spread of this group. Westward it gave the first cottons of Africa (race *soudanense*); eastward it gave the cottons of the Ganga Valley, Assam, Burma, Indonesia, the Philippines and China (races *bengalense*, *cernuum*, *burmanicum* and *sinense*). Hutchinson *loc. cit.* also considers, on genetical, morphological and geographical grounds, that *G. arboreum* in Madagascar was derived from the Peninsular Indian forms of *G. arboreum* race *indicum*.

Of the other Old World diploid species of cotton, viz., *G. herbaceum*, only the annual forms belonging to the race *wightianum* are grown in Peninsular India. They are believed to have been introduced into western India from Arabia or the coasts of Persia and Baluchistan (Hutchinson, 1954). *Gossypium arboreum* and *G. herbaceum* are so closely related that they give vigorous fully fertile F_1s, and the species barrier only acts through genetic breakdown in later generations. Silow (1944a) considers, on genetical evidence, that the race *indicum* of *G. arboreum* has greater affinity with *G. herbaceum* than with most other races of present day *arboreums*, suggesting that this race has diverged less from a common prototype than other sections of the species. Hutchinson (1954) is of the view that *G. arboreum* was never truly wild, but evolved in cultivation by differentiation from a cultivated stock of *G. herbaceum*. On any theory of differentiation of these two species, Rozi, (*G. arboreum* race *indicum*), a perennial cotton from western India and the perennials of *herbaceum* race *acerifolium* from Arabia, are regarded as the forms interlinking them (Hutchinson, *loc. cit.*).

Gossypium hirsutum was first introduced into India in the latter half of the 18th century. Today, the annual Upland and the Cambodia cottons, belong-

ing to *G. hirsutum* race *latifolium*, constitute the major source of quality cottons in India. The Uplands belonged to the United States Cotton Belt and were introduced into this country by the East India Company in the middle of the 19th century (Gammie, 1908). The Cambodias were introduced in Madras State in 1906 (Anon., 1954); their origin can be traced by way of Cambodia and other parts of South-east Asia to direct introduction by the Spaniards from Mexico to the Philippines (Lewton, 1925).

In spite of several attempts made, since 1931, for the introduction and acclimatisation of *G. barbadense* L. in India, this species has hardly ever thrived in this country. Only recently, it has been claimed to have been successfully grown, though on a small scale, as an unirrigated pure crop on the coastal strips of the present States of Kerala and Mysore (Kalyanaraman *et al.*, 1955), and the variety, 'Andrews' has been adopted for cultivation in this area (Sethi, 1956).

The efforts which the East India Company made to introduce foreign cottons into this country may be considered as an important landmark in agricultural experimentation. However, systematic improvement of the crop on scientific lines began only about 50 years back. Nevertheless, considerable progress has been made in tackling the problems of cotton growing and improvement in the country.

PROBLEMS OF COTTON IMPROVEMENT

In India, cotton is grown under diverse conditions of soil and climate. It is cultivated over a latitudinal range extending from 9° to 33° N. and in altitudes varying from riverine and coastal plains to plateau and highlands up to *ca.* 3,000 feet above sea-level. The variety of soil types include alluvial sandy loams in northern India and black cotton soils, clayey red loams and coastal alluviums in Peninsular India. It is primarily grown as a rainfed summer (*kharif*) crop in areas with an annual precipitation of 20 to 100 inches most of which is received during a brief four-month period extending from June to September. Only in those southern parts of Peninsular India, i.e., in parts of Andhra Pradesh, Madras and Mysore States, where good quantities of winter rains are received, winter crops of cotton are grown. Due to vagaries of the monsoons, the rainfall is usually ill-distributed and consequently the crop often suffers from drought or from excessive and untimely rains. Certain cotton tracts, such as the western areas of the Deccan Plateau in Bombay, Mysore and Andhra Pradesh States and the central region in Rajasthan, are proverbially droughty areas. The hardy, deep-rooted Old World species of cotton, *G. arboreum* and *G. herbaceum*, exhibit remarkable adaptability to these widely divergent conditions. As a result of the increasing demand for quality cottons in the country, *G. hirsutum* is gaining popularity, but it can be grown

only in areas where rainfall is assured or facilities for irrigation exist. With the execution of the major and minor irrigation projects envisaged under the Five-Year Plans, the area under *hirsutum* cottons in India is likely to increase substantially.

The wide range of soil and climatic conditions under which cotton is grown in India exercises considerable influence on cotton breeding programmes. In most States no single type is found suitable for cultivation over the entire region. Often more than one variety or strain of a particular species had to be recommended within a tract to suit local conditions. The existence of several agrotypes in a particular region is not desirable, as it complicates the work of maintenance, multiplication and distribution. Therefore, the breeder aims at evolving a plastic strain which would be adapted to as large an area and as great environmental diversity as possible, and yet conform to the requirements of the trade.

The experience with Cambodia cottons (*G. hirsutum*) in Madras State would illustrate this point. The strain Co. 2 (=Cambodia 2=Coimbatore 2) was evolved in 1929. It was suitable for winter cropping under rainfed or irrigated conditions. Further work aiming at the improvement of staple length in Madras Cambodias, resulted in the evolution of three more strains Co. 3, Co. 4 and 4463 which were discovered to be highly suitable for growing in distinct agro-ecological zones: Co. 3 in Salem district, both under rainfed and irrigated conditions; Co. 4 as a summer crop in tankfed rice lands of southern districts; and 4463 as a substitute for Co. 2 in Coimbatore *tehsil* for the intensive sorghum-cotton cropping practised in that area. However, by 1943 it was felt that the State had too many *hirsutum* strains under cultivation. Further selection work in Co. 4, resulted in production of the strain, Madras Cambodia Uganda 1 (M.C.U. 1) which proved suitable for whole of the wide range of environmental conditions adopting different crop sequences and planting dates (Anon., 1954). A similar situation obtains in the *arboreum* cotton in Karunganni tract of Madras State, where the strains, Karunganni 2 (K.2) and Karunganni 5 (K.5) suited to the southern and central districts, respectively, are sought to be replaced by a universal type (Kalayanaraman, 1955) like 6186-9 (Santhanam, 1958b).

Requirement of indigenous and international markets has also had its impact on the objectives aimed at by the breeder. So long as quality was not an important consideration and the export trade took whatever was grown, yield and ginning outturn were the principal concern of the grower and the tradesman. In the years following the First World War, need was felt for growing better staple cottons in the country. The Indian Central Cotton Committee, established in 1921, soon became a common meeting ground for all sections of cotton industry and scientists of the various Departments of Agriculture and increasing attention began to be paid to quality in cotton breeding. Cash value is the best criterion in judging the merit of a cotton

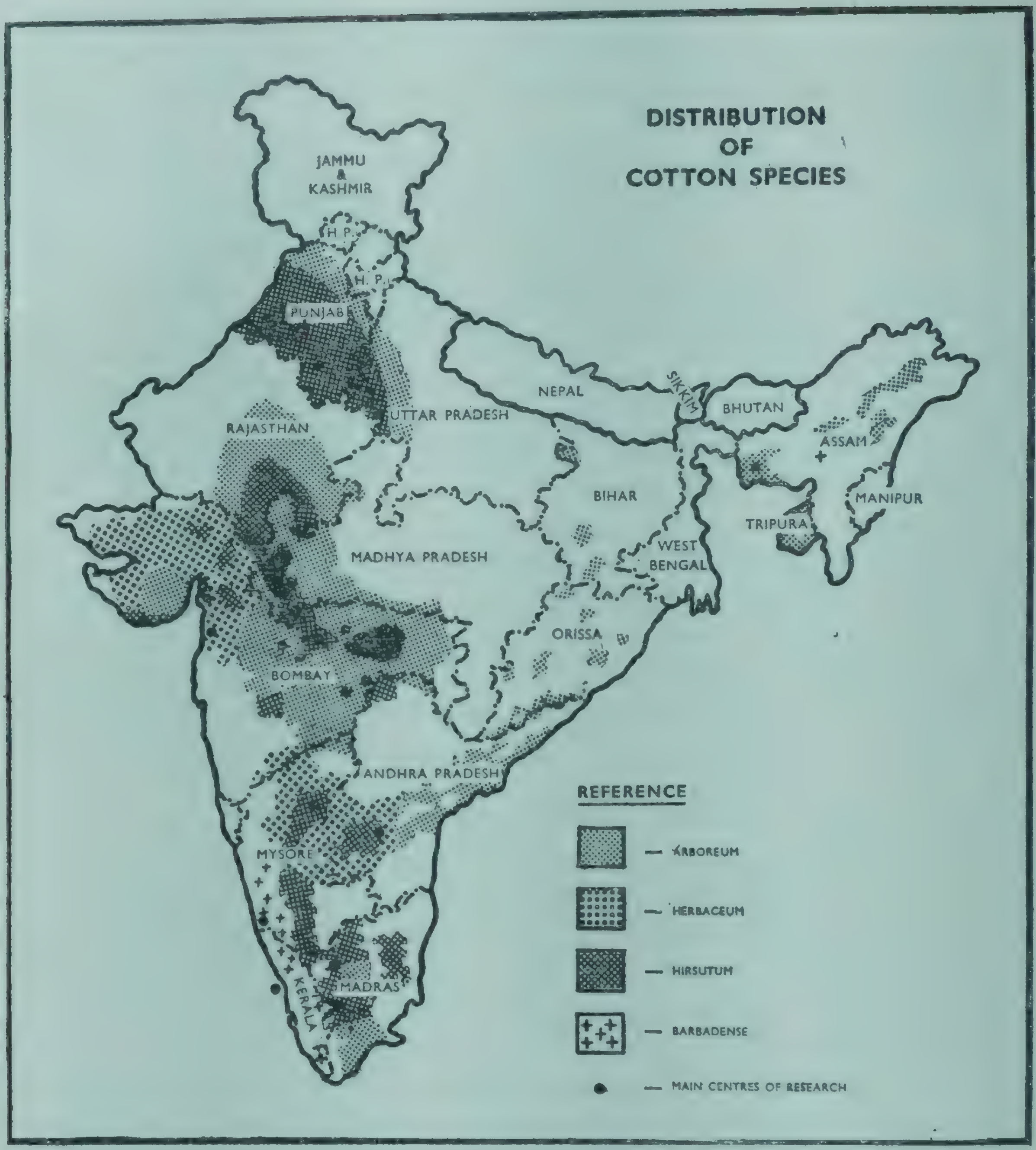


Fig. 18. Cotton Species grown in different parts of India

variety. The three principal characters of economic importance are, yield of seed cotton per acre, ginning outturn and staple length. Breeding work was, therefore, directed towards evolving quality strains that would ensure the farmer high cash returns per acre (Panse, 1941a). The case of Garo Hill (*arboreum* race *cernuum*) cotton of Assam illustrates how even a short staple, coarse cotton may receive preference over quality cottons on economic grounds. This cotton is an important earner of foreign exchange, as it is largely used abroad for mixing with wool or other cottons for making cloth. For this reason, the continued cultivation of this cotton in Assam was recommended in preference to long staple cottons (Datar Singh, 1953) (Fig. 18).

Breeding for Yield and Other Characters

In the case of cotton, genetic improvement is necessary both for increasing yield and for upgrading quality. Success or failure of cultivation depends probably more on the variety chosen for planting than on any other single factor, although it is true that yield as well as quality are also largely influenced by environmental and cultural conditions. The various factors, which have to be reckoned with by the breeder are briefly dealt with below. For a detailed treatment, the reader is referred to Christidis and Harrison (1956).

YIELD

Yield is a major factor governing cash returns per acre and hence it largely determines the agricultural value of a variety or improved strain. The production capacity of a variety is subject to considerable variation according to environment. In view of the wide fluctuations in range of soil and climatic conditions prevailing in the cotton growing tracts in the country, adaptability of a variety to a tract as a whole, or to an agro-ecological zone within a tract, is very important. This is usually assessed by studying the comparative performance of a common set of varieties or strains at a number of stations over a sequence of crop seasons. A study of the response of varieties, or genotypes, to cultural conditions, such as, sowing date, fertilizers, irrigation, and spacing (Christidis and Harrison, 1955; Turner, 1944) is also of much importance to the breeder.

The various factors which govern yield and quality in this crop, and in respect of which heritable differences between varieties are known to exist, are discussed below.

Stand. This is the number of plants available for harvest in the field per unit area after gaps have been caused by defective germination, seedling and plant mortality due to environmental and cultural conditions and incidence of pests and diseases. Yet, varieties are known to differ significantly in the maintenance of stand. Incidence of diseases, such as wilt, and pests like the stem weevil would obviously affect final stand; varietal resistance to these hazards is known.

The germinability of the seed is influenced by the toughness of seed coat, degree of fuzziness and prevalence of seeds with immature embryos which are all varietal characteristics. Varieties are also known to differ in respect of germinability under varying conditions of temperature such as those obtained in temperate countries.

Flower Production. Varieties differ not only in respect of earliness in the initiation of flowering, but also with regard to peak period of flowering, total flower production per plant and shedding of squares and flowers. Flower production depends on the number of flowering branches (sympodia) per plant and the number of flowers per branch. Workers in Egypt and West Indies (Balls and Halton, 1915; Harland, 1918) found that the yield of cotton was primarily dependent on the number of flowers produced. However, observations made in the Punjab (Afzal, 1941a) indicated that this relationship did not hold good. The percentage of shedding of forms (squares, flowers and bolls) is often more important than flower production in determining yield, as the correlation between the number of flowers and the final number of bolls, produced is generally not high. In India, the cotton crop of the summer season usually comes into flowering when the temperatures are still high and considerable shedding of forms takes place (Joshi *et al.*, 1941). Although shedding is largely influenced by environmental conditions and by incidence of diseases and pests, varietal selection for the non-shedding character is possible. In breeding for non-shedding varieties, forms should be chosen in which transpiration, rate of photosynthesis, formation of vitamins and suction pressure of the buds and bolls are high and the root system is well developed (Christidis and Harrison, 1955). A study of intensity of flowering in relation to climatic conditions during the flowering period is also important in breeding for yield. A variety which does not have its peak flowering during an unfavourable period is likely to yield better than others; selection in this direction can lead to improvement in yield (M. L. Patel, 1941).

Boll Number and Boll Weight. The number of bolls produced per plant bears the closest relation to the yield. It is the net outcome of flowers produced, and flowers and bolls shed. Genotypic selection for ripe bolls, therefore, results in the selection for productivity. 'Bad opening' of bolls, often caused by environmental factors and incidence of pests and diseases, is responsible for deterioration in lint yield and quality. Since varietal differences for this character also are known, it can be selected against by taking into account only the bolls with good opening.

For the same number of ripe bolls produced, final yield is directly proportional to boll weight and not to the actual dimensions of the boll. Boll weight is expressed as weight of seed cotton per boll and on this basis varieties are classified as large, medium or small bolled. Apart from the contribution

they make to yield, larger bolls are also advantageous in that they are more easily picked than smaller ones and there is comparatively lesser trash collected.

The Old World cotton species have smaller bolls than the New World ones. In the Indian *arboreums* the boll weight ranges from 0·8 to 2·6 gm. and in *herbaceums*, from 1·0 to 2·6 gm. (Ramiah, 1948). In *hirsutums* the known range of boll weight is much wider, extending from about 3 gm. to as high as 10 gm. (Hutchinson, 1951). Boll weight in Egyptian (*barbadense*) cotton is known to vary around 3 gm. only. Even within varietal limits, genetic variability in respect of this character is known to exist. Continuous selection for heavy boll can, therefore, be effective. Such selection in Gaorani cotton (*G. arboreum*) in India resulted in the selection of a high yielding, larger bolled strain, 1494 (Bederker, 1955b). In this connection, it should, however, be noted that it may not be advisable to select for a boll size larger than that which would be optimum for the soil and climatic conditions prevailing in particular tracts, as undue emphasis on this character is likely to affect fibre properties, especially fibre maturity. In cotton breeding programmes it is often useful to determine the optimum boll size for a particular agro-ecological region as in the case of Tungabhadra Project area of Mysore and Andhra Pradesh States (Harland, 1955a).

Earliness. The time taken from sowing to the commencement of flowering can indicate the earliness or lateness of a variety. This criterion is, however, not always reliable; a type, though by no means the first to start flowering, can rush up later to a very early and very high flowering peak. The date of peak flowering can, therefore, be a measure of earliness (Brown, 1951). The node at which the first sympodial branch is borne, is also an index of earliness; the lower such node is on the main stem, the earlier is the variety.

Cotton does not all ripen simultaneously, but over a period of two months or more. Therefore, date of commencement of flowering or peak flowering or date of the bursting of the first boll can be regarded as only indicative of earliness. Other methods of assessing earliness of maturity have, therefore, been recommended. These are :

(*i*) *Percentage of First Picking:* This method is most commonly applied. It consists in determining the percentage of the first picking to the total. However, in this way the amounts harvested at each later picking are not taken into account separately, which results in considerable loss of information. Moreover, the date for first picking might have been fixed quite arbitrarily. In the U.S.S.R., earliness is usually determined by the number of days from sowing to the ripening of 50 per cent. of the bolls. However, results from such observations were found to be rather contradictory (Christidis and Harrison, 1955).

(ii) *Bartlett's Rate Index:* According to this widely used method (Bartlett, 1937), the earliness is assessed on the basis of: (i) number of bolls or preferably; (ii) weight of seed cotton (*kapas*) obtained at every picking. In the latter case the following formula is used for determining the rate index:

$$\frac{(P_1) + (P_1 + P_2) + \ldots\ldots\ldots\ldots + (P_1 + P_2 + \ldots\ldots + P_n)}{n\,(P_1 + P_2 + \ldots + P_n)}$$

where,
P_1, P_2 ...... P_n are the weight of seed cotton collected in 1st, 2nd .... n^{th} picking and n is the number of pickings taken.

The earlier the type, the nearer unity will be the value of rate index for it.

(iii) *Mean Date of Maturity:* This character seems to be a very useful index of earliness, as it is based on data relating to each one of the pickings, although the dates of picking might have been fixed arbitrarily. The value for mean date of maturity (Christidis and Harrison, 1955) can be obtained by using the following formula:

$$M.D. = D + \frac{\sum (x.d)}{\sum x}$$

where,
M.D. = Mean date of maturity.
D = Date of origin or date of maturity of the bolls for first picking. This is exactly intermediate between the date on which numerous bolls start opening and the date on which first picking is actually taken; both the latter dates are, of course, arbitrarily fixed;
d = Number of days from D to the date of maturity of the bolls for each picking. Bolls for a particular picking, excluding those for the first picking, are considered to have matured on a date exactly intermediate between the date on which they were picked and the date on which the immediately previous picking was taken.
x = Amount of seed cotton picked at each picking.

The following example relating to the variety Acala, adapted from Christidis and Harrison (1955), will illustrate the use of the above formula.

Pickings	No. Date	I Sept. 19	II Oct. 5	III Oct. 15	IV Nov. 7	V Dec. 10	Total
Weight of seed cotton picked (lbs.)=x		431	593	535	379	148	2,086
Dates of maturity of bolls for each picking		Sept. 11·5	Sept. 27	Oct. 10	Oct. 26·5	Nov. 23·5	
d		0	15·5	28·5	45·0	73·0	

September 4 = Date of ripening of numerous bolls prior to first picking.
Date of maturity of bolls for:
(i) first picking:

$$D = \text{Sept. } 4 + \frac{(\textit{Days from Sept. 4 to Sept. 19=15 days})}{2}$$

$$= \text{Sept. } 4 + 7{\cdot}5 \text{ days}$$
$$= \text{Sept. } 11{\cdot}5$$

(*ii*) second picking:

$$= \text{Sept. } 19 + \frac{(\textit{Days from Sept. 19 to Oct. 5=16 days})}{2}$$

= Sept. 27

(*iii*) third picking:

$$= \text{Oct. } 5 + \frac{(\textit{Days from Oct. 5 to Oct. 15 = 10 days})}{2}$$

= Oct. 10

and so on for the other pickings.

d (for first picking) = Days from Sept. 11·5 to Sept. 11·5 = 0

d (for second picking) = Days from Sept. 11·5 to Sept. 27 = 15·5

d (for third picking) = Days from Sept. 11·5 to Oct. 10 = 28·5

and so on for the other pickings.

$$\text{M.D.} = \text{Sept. } 11\cdot5 + \frac{[(431 \times 0)+(593\times15\cdot5)+(535\times28\cdot5)+(379\times45\cdot0)+(148\times73\cdot0) \text{ days}]}{2086}$$

= Sept. 11·5 + 25·1 days.

= Oct. 6·6

PICKING QUALITIES

Cotton is entirely hand-picked in India. In advanced foreign countries like the U.S.A. and the U.S.S.R., mechanical picking, using stripping machines and spindle-type pickers, is widely practised.

It has been noticed that varieties of cotton differ with regard to the way in which they open their bolls. Large bolls make for easy and economical picking. The easiest to pick are those varieties in which the bolls flare back on ripening and the seed cotton is fully exposed. However, in such varieties, the cotton is liable to damage by heavy rains or strong winds when still borne on the plants. In some varieties, which are termed 'storm proof', the locks are moderately firm and cling well together, their proximal tips are held in the bolls rather severely. The burs are also stiff and on opening, which is not complete, they assume a cup-like form, hang down, and protect the locks against rain. An extreme example of storm proofing is provided by the Wagad cotton (*G. herbaceum*) in Kutch and northern Kathiawar region of Bombay State. In this cotton, the bolls scarcely open at all, so that the locks are protected against strong winds prevalent during picking time.

Hairy leaves and large-toothed bracts contribute materially to trash in the lint. In the U.S.A. and the U.S.S.R. breeding for smooth leaves and small bracts has led to the evolution of varieties giving clean pickings; in this work, use has been made of *marie-galante* cottons (*G. hirsutum* race *marie-galente*) which possess small, almost toothless bracts (Christidis and Harrison, 1955). Such types are particularly useful for mechanical picking. In *G. arboreum* a vestigeal bract mutant, which might be useful in breeding work, has been described by Joshi (1956a).

LINT/SEED RATIO

The ratio between lint and seed is of considerable economic importance. Estimates of this ratio are given by ginning percentage or lint percentage,

which is the weight of lint as a percentage of the weight of seed cotton, and lint index which is the weight of lint per seed, or per 100 seeds. Ginning percentage is given by the formula :

$$\text{Ginning percentage} = \frac{\text{Weight of lint}}{\text{Weight of seed cotton (i.e., lint + seed)}} \times 100$$

Lint index may be computed as follows:

$$\text{Lint index} = \frac{\text{Weight of 100 seeds} \times \text{Ginning percentage}}{100 - \text{Ginning percentage}}$$

Deo (1953) has prepared a simple balance, useful to cotton breeders, which directly and accurately gives the ginning percentage value for small quantities of seed cotton.

Ginning percentage is a composite character. It depends primarily on seed weight and lint weight. Seed weight is determined by the seed volume and specific gravity, while lint weight varies according to the number of fibres per seed, and the weight of individual fibres. The latter in turn depends on lint length, lint thickness and specific gravity of the fibre walls. Ginning percentage is augmented either by decrease in seed weight or by increase in lint weight. It does not by itself give precise information about the total production of lint when a number of genotypes or varieties are under study. Selection for high ginning value may often result in the evolution of types with light (small) seeds without necessarily stepping up lint production per seed, and hence per plant and per acre. As early as the year 1908, Cook stressed the danger of persistent selection for ginning outturn ; he stated that although smaller seeds raise the ginning outturn, larger seeds have several advantages.

Lint index represents the absolute weight of lint produced per seed and this character is, therefore, considered by some breeders to be more useful in breeding work than ginning percentage (Anon., 1943). Harland (1934a) showed that in Sea Island cotton (*G. barbadense*), lint index is strongly correlated with yield. Recently, he has observed that in cotton breeding in India, lint index should receive special emphasis in selection programmes. Lint index is, however, positively correlated with seed weight (M. L. Patel, 1922 ; Afzal, 1930 ; Kelkar *et al.*, 1947b). In the improvement of lint index, therefore, if the increase in seed weight is not compensated for by the number of fibres per seed, staple length or fibre weight, then such uncompensated increase in seed weight is likely to affect ginning percentage, although in most cases lint index is positively correlated with ginning percentage (Hodson, 1920 ; Stroman, 1949). It would, therefore, appear that, while from the breeders' point of view, selection should be primarily based on lint index,

ginning percentage should not altogether be overlooked as the market value of cotton is governed by ginning outturn.

The rank of cotton varieties with respect to their ginning outturn varies but little from season to season or from place to place. The variation in ginning value of different cottons is given in Table 25.

TABLE 25. GINNING VALUE OF DIFFERENT COTTONS

Species		Ginning percentage
G. arboreum		
India		22-56 (Table 50)
G. herbaceum		
India		23-47 (Table 50)
G. hirsutum		
India		28-38 (Table 50)
U.S.A.	Mostly	30-40 (Christidis and Harrison, 1955)
G. barbadense		
Egypt		30-40 (Brown, 1953: Fikry, 1953; Christidis and Harrison, 1955)

Number of Fibres per Seed. Ginning outturn is, undoubtedly, very much influenced by the number of fibres per seed although the direct relationship between these two characters has been a matter of controversy (Balls, 1915 ; Burd, 1924 ; Turner, 1929). Selection for this character should be helpful in improving lint index, provided increase in the number of fibres is not achieved at the expense of fibre maturity and staple length.

The actual number of fibres per seed may vary according to the type of cotton studied, the method used for its determination and according to the investigator. However, some of the results reported so far are instructive.

Type of cotton		Number of hairs per seed	Authority*
G. indicum	(=*G. arboreum* race *indicum*)	3,700	R. L. N. Iyengar, 1934
G. indicum		4,000—6,000	Turner, 1929
G. roseum	(=*G. arboreum* race *bengalense*, genetic type *roseum*	5,900—7,000	,,
G. cernuum	(=*G. arboreum* race *cernuum*)	11,000—11,800	,,
G. hirsutum		7,900	,,
G. hirsutum		14,700	R. L. N. Iyengar, 1934
G. barbadense	(Egyptian)	8,000	Balls, 1915
G. barbadense	(Sea Island)	11,700—16,400	Burd, 1924

* Data from Christidis and Harrison (1955).

The fibre population is densest at and near the chalazal area of the seed, becoming thinner downward towards the micropylar end and outward towards the raphe.

It may be interesting to note that *G. arboreum* race *cernuum* has been used in India for improving the ginning value of *arboreum* and *herbaceum* cottons.

The average number of fibres per seed may be determined in various ways. Best results seem to be obtained by the simple method of dividing lint weight per seed by the mean weight of individual hairs, provided the latter is based on a sufficiently large number of fibres representative of the whole sample. The method suggested by Turner (1929) takes into account fibre length distribution as given by a cotton sorter and fibre weight per inch for the different hair lengths. This method is quite accurate but may be somewhat affected by variation in the fibre weight along the length of the fibre. Another way is to divide lint weight per seed (Lint index) by the product of mean fibre length and mean fibre weight per unit length; this method, however, gives two to three per cent. lower estimate of the value.

LINT QUALITY

Improvement in the quality of cottons is a pressing problem in India. Successful establishment of superior quality strains, however, depends on their ability to increase the return per acre to the cultivator. Return per acre is an integration of two components, the premium obtainable for quality and the yield of lint per acre. Both factors must, therefore, be considered together in cotton breeding.

The ultimate index of quality of a cotton lies in its spinning value. Although it is true that the optimum spinning performance of a cotton is largely influenced by the type of machinery used, spinnability is a varietal characteristic. The ideal cotton would possess long, bright, lustrous lint, the fibres being all of the same length, strength, diameter and wall thickness, and having the same number of convolutions in the same direction and spaced at equal intervals from end to end. Such cotton would spin most economically (without much waste), would produce yarn of maximum resistance to slip, and would take dyes very uniformly. Such a perfect cotton is of course unattainable, but strains can be selected for a combination of fibre properties which would give the best possible spinning performance. Among the fibre properties contributing most to spinning value are lint length, fibre weight and strength (Turner and Venkataraman, 1933 ; Barker and Pope, 1948). Breeding work has so far been carried out using mostly the above properties. A micro-spinning test evolved in Egypt has been adapted for cottons grown in India (Sen, 1948) and, therefore, it is now possible for the breeder to base his selection on actual spinning performance.

The range of spinning value and of characters important to spinning performance in the Indian cottons, including breeders' strains, is given in Table 26.

TABLE 26. SPINNING VALUE OF DIFFERENT SPECIES

Species	Mean fibre length (inch)	Mean fibre weight per inch (10^{-6} oz.)	Spinning value (highest standard warp count)
G. arboreum	0·50 — 1·14	0·355 — 0·140	6 — 44
G. herbaceum	0·75 — 1·10	0·232 — 0·147	8 — 43
G. hirsutum	0·80 — 1·33	0·155 — 0·084	14 — 56

Fibre Length. From the economic point of view, the most important among fibre properties is lint length. This character is determined in a number of ways from the Pulling Method for Graders' Length, which is a professional estimate based on eye and hand judgement of the cotton classers, to the length measurements recorded by means of a transparent celluloid disc placed on halos combed out (Bailey, 1930) and finally the accurate determination of mean fibre length by means of fibre sorting instruments like the Ball's Sorter or the Baer's Sorter, or by modern photo-electric instruments such as the Fibrograph.

The methods employed for lint length measurements by cotton breeders in India have been numerous and varied (Hutchinson *et al.*, 1938 ; Panse, 1938 ; Iyengar and Ahmad, 1947 ; Iyangar and Sen, 1956). At Surat, lint obtained from seed cotton was, in earlier years, measured in the manner similar to that followed by a grader. At other places, and also at Surat subsequently, all or half of the fibres on the seed were combed out in the form of a halo or a butterfly and measurements were made at specific points using a Bailey's disc, in its original or modified form, or a pair of dividers and a scale. After analysing these methods, Panse (1938) advocated the use of Indore method by which "a bunch of the longest fibres producing a clearly visible edge" on the combed halo is measured. Iyengar and Sen (1956) examined the techniques adopted at the various breeding stations in India and suggested a standard procedure which is outlined below :

1. From each lot of seed cotton, 5, 10 or 22 seeds are sampled out. With larger samples the statistical significance of smaller differences can be judged.
2. Fibres on the right side of each seed (keeping its pointed end forward and the raphe upward) are combed out in the form of a halo.
3. The halo is mounted on a velvet board and readings are taken at three points on the three radial lines marked out on the standard halo disc. The mean of the three readings represents the halo length for the seed.

The mean values obtained for halo length of different lots of seed cotton by this technique are directly comparable to the machine length, i.e., mean fibre length.

The range of mean fibre length of improved varieties of the three cotton species grown in India, which have been released for cultivation is shown in Table 27 ; for the sake of comparison, the range of corresponding values available for some of the improved foreign varieties of *G. hirsutum* (Fikry, 1953; Christidis and Harrison, 1955), are also given (Plate xix).

TABLE 27. FIBRE LENGTH OF IMPROVED VARIETIES

Species	Mean fibre length
G. arboreum	
India	0·61″ — 0·89″ (22·7 mm.)*
G. herbaceum	
India	0·79″ — 0·98″ (24·9 mm.)*
G. hirsutum	
India	0·84″ — 0·97″ (24·8 mm.)*
U.S.A.	19 — 22 to 30 — 35 or even 50 mm. (Mostly 25 — 28 mm.)
U.S.S.R.	22 — 25 to 27 — 30 mm. (Mostly 24 — 27 mm.)
G. barbadense	
Egypt	26 to 40 mm.
U.S.A. (Pima)	39 to 50 mm.

*Quinquennial averages

As will be seen from Tables 26 and 27, higher fibre lengths have been attained in some of the breeders' strains undergoing performance tests. Breeding for increased fibre length is, today, one of India's foremost cotton improvement problems.

Fibre Diameter and Fibre Weight. Cotton with a soft and silky feel is considered to be fine. This character is determined by hair cell diameter and by wall thickness, assuming a constant density of wall material. Actual hair diameter measurements are useful in breeding for fineness and various methods have been described for determining this character (Sen, 1948).

A hair properly thickened looks thinner and is certainly of better quality than if it remained thin-walled. Fineness then becomes synonymous with good maturity and hair strength. Hence the importance of fibre weight per unit length, which constitutes one of the most important criteria for selecting cottons of better spinning value. A rapid method of sampling for fibre weight determinations was described by Panse and Sahasrabuddhe (1943). The most modern instruments, such as the Arealometer and the Micronaire which use the air-flow method for the rapid and accurate determination of fineness on samples as small as 8 gm. would be very useful to the breeder in selecting for this character.

It may be mentioned that, recently, in the breeding work on *hirsutum* in the Punjab, some fine linted strains, with mean fibre weight as low as $0{\cdot}084 \times 10^{-6}$ oz., have been evolved.

Fibre Strength. Yarn strength is not determined entirely by the strength of the individual fibres; it also depends on the way the fibres twist

about one another and cling together. The latter property is determined by fibre length, fineness and convolutions. However, there is now evidence to suggest that yarn strength is more correlated to hair strength than to almost anything else (Christidis and Harrison, 1955). Pressley's Fibre Strength Tester (Pressley, 1942) is a handy and useful instrument for quick determination of fibre strength. In the U.S.A., it was only after the invention of this machine that considerable progress was made in breeding high quality cotton varieties (Bederker, 1950). In cotton improvement work at Raleigh, North Carolina (U.S.A.), the chief aim from the immediate economic point of view has been the improvement of fibre strength in the Upland *hirsutums*. From a long range point of view the same work shows that the possession of a greatly extended range of fibre types offers increased opportunities for analysing the complex system of interdependent variables which determines fibre and spinning quality. For instance, fibre strength has been found to be associated with narrow perimeter and low spiral angle, i.e., the angle at which the cellulose molecules in the cell wall are laid down in relation to its longitudinal axis. The wild species, *G. thurberi*, has been found to be a potential source of fibre strength. By successive backcrossing of the amphidiploid (*G. arboreum* x *G. thurberi*) to *G. hirsutum* it has been observed that fibre strength in cultivated *hirsutum* can be increased by about 30 per cent. without detrimental effect on spinning quality. Not only has this level of improvement been maintained over successive backcross generations, but it has been found that by critical selection in backcross progenies an improvement of as much as 80 per cent. in fibre strength can be achieved (Stephens, 1947a).

In India, however, the determination of the fibre strength as a routine breeding operation needs to be more widely practised than it has been hitherto. Pressley Fibre Strength Tester or the more modern instruments such as the Clemson Flat Bundle Tester and the Stelometer, would greatly accelerate the breeders' selection for this important character.

Fibre Immaturity. Although the maturity of fibres is considerably affected by cultural and environmental conditions this character is hereditary (Lord, 1948). The maturity of fibres can be tested under the microscope by the mercerisation technique using an 18 per cent. caustic soda solution or by means of stain techniques (Goldthwait *et al.*, 1950 ; Bhujang and Nanjundayya, 1953 ; Bhujang, 1957). A modern instrument, Arealometer, simultaneously and quickly determines fibre fineness and degree of immaturity (Hertel and Craven, 1951). Fully mature fibres show two stages of thickening; primary and secondary. Fibres with practically no secondary thickening are 'immature' or 'dead'. They cause the production of neps in spinning and affect the appearance of the yarn. Among Indian cottons, those belonging to *G. arboreum* seem to show high percentages of fibre maturity as compared to those belonging to the other two species. Also varietal differences

with regard to this character are noticeable in all the three species which indicate that it is possible to breed for improved fibre maturity.

Imperfections in Yarn. Lint, when spun into yarn, shows certain imperfections such as neps, which are knots of tangled cotton fibres and which contribute to unevenness of yarn and defective finishing and dyeing. Nep formation is dependent upon immaturity of fibres, inclusion of foreign particles in lint and manipulation of lint (Evenson, 1955). Structural deformities of fibre, such as kinks, spurs, knots and injuries also contribute to neppiness (Gulati, 1947). Neps caused by a small tuft of immature fibres are of the size of a pin-head but those caused by a larger tuft of immature fibres—matted fibres are bigger in size. Seed coat neps are caused by the fragments of testa detached usually from the chalazal end of the seed during ginning. Critical breeding work, aiming at the evolution of strains which are less liable to such seed damage and which possess increased fibre maturity, would lead to the production of nep-free varieties (Evenson, 1955). Ariyanayagam and Wijewantha (1956) have reported on the measure of success achieved by them in breeding against seed coat neppiness. Underwood (1955) has shown that the number of seed coat neps in the sample also depends on the number of seeds per unit weight of lint and has advocated breeding for high lint index for reducing seed coat neps. Motes, which are aborted structures from ovules failing to ripen into mature seed, also contribute to the immaturity of fibres and hence to yarn imperfections. Though fibre immaturity, proneness to detachment of testa during ginning and formation of motes are influenced by environment and though it is considered that neps are also caused by mere manipulation or handling, still varietal differences in regard to these characters are noticeable (Pearson, 1949 ; Lord, 1948 ; Evenson, 1955). There is a tendency for neppiness to increase with lint length and fineness besides fibre immaturity (Webb and Richardson, 1951 ; Regnery, 1952). Although, therefore, the problem of neppiness is sought to be tackled through technological improvements in handling and spinning cotton, yet it is perhaps as much a breeder's problem, especially in his task of breeding long stapled, fine cotton varieties.

Neps can be determined by actual counts (Jambunathan, 1956) in the lint and the yarn, using a number of simple instruments, such as Readex (Finley, 1945), Nepscope (Anon., 1946), and Scanning apparatus (Chamberlain and Jordan, 1956) devised for this purpose. Recently an instrument called Nepotometer, has been devised for predicting the nepping potential of cottons (Bogdan, 1954 ; Rouse, 1954).

Colour and Brightness of Lint. Cotton lint is mostly white or creamy white. Other colours observed are dirty grey, black, khaki and different shades of brown and green. In India white-linted cotton is grown extensively. The brown-linted *arboreum* varieties, Cocanadas and Red Northerns, were

at one time grown on a large scale in the Cocanadas and Red Northerns tracts (Andhra Pradesh) when they were in demand for their dyeing qualities. However, in recent years, they are sought to be replaced by more needed white lint types wherever possible.

In the U.S.S.R., cottons with shades of pink, red, blue, green and even black colour are reported to have been evolved. These varieties do not seem to have attained economic importance owing to low productivity or weakness of fibre.

SEED CHARACTERS

Seed Index. The seeds of *arboreum* and *herbaceum* are generally smaller than those of *hirsutum*, the range of 100-seed weight (Seed Index) for the Indian varieties being 5·1 to 6·7 gm. in *arboreum*, 5·4 to 7·5 gm. in *herbaceum* and 7·5 to 11·7 gm. in *hirsutum* (Nanjundayya, 1956). In *hirsutum*, seeds with improperly developed embryos are usually met with; this affects not only the quality of lint on them, but also their germinability. Selection for higher seed weight ensures evolution of types with properly developed seeds and it may lead to the improvement of lint index also. Selection for low seed weight, if not at the expense of embryo-maturity, would be conducive to higher ginning.

Fuzziness. Two types of unicellular hairs develop on the cotton seed : (*i*) long fibres which are spinnable; and (*ii*) short hairs which are non-spinnable (Hock, 1947 ; Hafiz, 1951). The latter make up the fuzz on the seed. Fuzziness of seed is an inherited character. With regard to the presence and density of the fuzz, cotton varieties and species exhibit considerable variation, ranging from the completely naked, black-seeded types to densely-fuzzy ones. Hutchinson *et al.* (1938) recognised eight grades of fuzziness and seven grades of fuzz colour in *G. arboreum* and *G. herbaceum* and ten grades of fuzziness and seven grades of fuzz colour in *G. hirsutum*. Thus the range of fuzziness in *hirsutum* exceeds that in *arboreum* and *herbaceum*. The fuzz colour grades cover shades of white, grey, brown and green. Varieties with naked or less fuzzy seeds usually germinate quickly, probably because their seeds absorb moisture more easily than do those of the fuzzier types. Some attempts appear to have been made (Bederker, 1950) to breed fuzzless *hirsutum* types with a view to encouraging the use of cotton seed as cattle feed. However, it has to be considered that cotton seed fuzz (linters) has several industrial uses (Nanjundayya, 1952). Linters have been found to be very suitable for the manufacture of high grade artificial silk, acetate rayon (Bederker, 1955c). Therefore, fuzziness of seed is economically desirable. To obtain good germination in field plantings done with the help of a drill, fuzzy seeds are soaked in water for about six to eight hours and the fuzz loosened by rubbing the moist seed on hard ground in a mixture of earth and cowdung.

Oil Content. Major part of the economic value of cotton seed is due to its oil content (Nanjundayya, 1952). In recent years hydrogenated cotton seed oil has been in commercial production for edible purposes in India. The old practice of using whole seed, of *arboreum* and *herbaceum* cottons in particular, as feed for the cattle, especially the milch cattle, is still in vogue. The feed value is both due to the oil content and the protein content. Cotton seed meal and cake left over after extraction of oil is considered to be a more wholesome feed for the animals, including cattle, horses, sheep, hogs, etc. (Athawale, 1944 ; Nanjundayya, 1952).

It is possible to evolve varieties of cotton with high or low oil content (Pope and Ware, 1945). Harland (1949) working in Peru with Tanguis cotton (*G. barbadense*), was able to raise its oil content from 21·8 to 29·2 per cent. without affecting the quality and quantity of the fibre. The improvement of oil content and of the nutritive value of the seed should, therefore, form a part of cotton breeding programmes. Some *hirsutum* varieties contain gossypol in concentrations high enough to be poisonous ; this aspect has, therefore, to be borne in mind during breeding work for improved oil content in cotton seed. Athawale (1944) determined the oil content of seed of different cottons grown in India and found the range to be extending from under 15.0 to 22·5 per cent. (see also Anon., 1957a). According to Christidis and Harrison (1955) varieties having naked seeds are superior in oil content to the fuzzy seeded ones. Egyptian (*G. barbadense*) black (naked)-seeded varieties rank first with about 25 per cent. oil ; next come naked-seeded *hirsutums* with 23 per cent. whereas fuzzy-seeded *hirsutums* contain between 18 and 21 per cent. of oil. Regarding oil content in relation to protein content, Pope and Ware (1945) found that the two were independent of each other so far as genetic constitution is concerned.

DISEASES AND PESTS

The following are the important diseases and pests of cotton in India. Breeding disease and pest-resistant varieties constitutes the best and the most economic method of controlling them.

Diseases :

1. Wilt—*Fusarium vasinfectum* Atk.
2. Root rot—*Rhizoctonia solani* Kuhn, and *R. bataticola* (Taub.) Butler. [*Macrophomina phaseoli* (Maubl.) Ashby].
3. Anthracnose—*Collectotrichum indicum* Dast.
4. Bacterial blight ; Blackarm, Bacterial boll rot or Angular leaf spot—*Bacterium* (*Xanthomonas*, *Pseudomonas* or *Phytomonas*) *malvacearum* Smith.

Pests :

1. Pink bollworm—*Platyedra* (*Pectinophora*) *gossypiella* Saund.

2. Spiky, Spiny or Spotted bollworm—*Earias insulana* Boisd. and *E. fabia* Stoll.
3. Jassids—*Empoasca* (*Chlorita*) *devastans* Dist.
4. Stem borer—*Sephenoptera gossypii* Cotes.
5. Stem weevil—*Pempherulus affinis* Fst.
6. Leaf roller—*Sylepta derogata* Fabr.
7. Aphis—*Aphis gossypii* Glov.

Wilt. The *Fusarium* wilt is one of the most destructive diseases of *desi* cottons (*G. arboreum* and *G. herbaceum*) in India. The *hirsutum* varieties grown in this country seem not to be attacked by this disease. Considerable success has been achieved in breeding wilt-resistant varieties of *desi* cottons, especially as a result of standardisation of the technique for testing cotton material under artificial conditions of infection and a large number of resistant varieties which include Jarila, H. 420, Virnar and others in *arboreum* and Jayawant, Vijay, Suyog, Kalyan, Jayadhar, Digvijay, and Vijalpa in *herbaceum*, have been developed in different parts of India (Kulkarni, 1934 ; Uppal, 1938 ; Uppal, Kulkarni and Randive, 1941 ; Patel and Bhat, 1953). According to Sawhney (1951), these wilt-resistant varieties covered over 17 lakh acres and they helped in saving the crop valued at about Rs. 68 lakhs annually, from ravages of this disease.

Blackarm. The blackarm disease occurs in all *hirsutum* growing areas in India and it assumes serious proportions in South India, particularly in years of heavy and continuous rainfall. Some varieties of *arboreum* and *herbaceum* can also be attacked by this disease which, however, does not seem to constitute a serious problem in India so far as these species are concerned. Various techniques have been devised for inoculating plants in the field and testing their resistance to the disease (Knight and Clouston, 1939 ; Simpson and Weindling 1946 ; Weindling, 1948 ; Bird and Blank, 1951). According to Kramarenko (1949), resistance to blackarm is due to a specific bactericidal property of the cell sap. Thiers and Blank (1951) reported that there are no essential differences in development of the disease in susceptible or resistant varieties, except in the number of bacteria and extent of the lesion; resistance appears to be due to a physiological incompatibility between host and parasite. Balasubrahmanyan and Iyengar (1952) have reported on the breeding work done in South India for the production of blackarm-resistant strains in *G. hirsutum*. In the classical work done by Knight and his associates in the Sudan, as many as nine genes for resistance to blackarm were recognised in *arboreum*, *herbaceum*, *anomalum*, *hirsutum* and *barbadense* (Knight and Clouston, 1939, 1941; Knight, 1954a, 1956) and the desirable genes were successfully transferred to the variety Sudan Sakel of *G. barbadense* (Knight, 1946a; Knight and Hutchinson, 1950 ; Knight, 1956).

Root rot. The root rot fungi are known to cause serious damage to cotton crops in India, especially in the Punjab and in Gujerat tract of Bombay State. Out of a large number of Indian, American, Egyptian and other varieties of cotton tested by Luthra and Vasudeva (1941) in highly infested plots, none showed any appreciable resistance to the disease. In Gujerat, however, continuous selection in *herbaceum* resulted in the development of families with a mortality of only 20 to 30 per cent. compared with 95 per cent. in the original variety (Govande, 1942). Among *arboreum* race *indicum* cottons, the perennial type, Rozi of Gujerat is known to be more or less immune to root rot (Balasubrahmanyan, 1950a). More recently, the technique for testing cotton material for this disease under conditions of artificial infection has been standardised in Bombay State and this might go a long way in helping the development of resistant varieties (Monitz *et al.*, 1956).

Anthracnose. The anthracnose disease is known to occur all over India and the damage to bolls by this disease is the greatest during years of heavy rainfall. The primary infection is seed-borne and disinfection of seed with hot water, sulphuric acid or Agroson G. N. is recommended as a control measure. Breeding for resistance to this disease does not seem to have been undertaken in India.

Jassids. Painter (1951) has given an excellent review of the work done on insect resistance in cotton.

Among the pests of cotton, greatest attention seems to have been given to jassids which is a pest of major importance particularly of the *hirsutum* cotton of India. Methods of evaluating jassid resistance were worked out by Verma and Afzal (1940). It has been found that resistance to this pest is highly correlated with the pilosity of the plant, the more resistant types showing a great degree of hairiness, i.e., length of hairs and density per unit area, on the underside of the leaf (Parnell *et al.*, 1945). Ahmad, Afzal and Ghani (1950) considered toughness of the vein to be associated with jassid resistance and these workers devised an apparatus for measuring this character. According to Afzal and Ghani (1953), hairiness of the leaf vein is the most important among the characters associated with jassid resistance. Working on the association between plant pilosity and jassid resistance, a number of resistant varieties of *G. hirsutum* have been developed in this country although there is still considerable scope for further improving the resistance to this pest.

An excellent example of successful handling of a gene complex is the interspecific transfer of high jassid resistance from Indian and Philippine varieties of *hirsutum* to Sudan Sakal, a fully susceptible variety of *barbadense* (Knight, 1956). The Hawaiian species, *G. tomentosum* ($2n$=52), is resistant to jassid attack owing to its high degree of pilosity. Knight (1954b) in-

troduced the gene for pilosity from this species into *G. barbadense*, but the same gene produced secondary effects of poorer plant growth and shortened lint and, as such, this gene was found to be useless from breeders' point of view. Another species reported to be jassid-resistant in Peru is *G. raimondii* ($2n=26$). At Indore, however, it is reported to be attacked by jassids, although the species is none the worse for the attack because of its very high vegetative vigour. Ganesan (1947) reported the production of amphiploid (*hirsutum* x *raimondii*) but no suitable types were derived by backcrossing it to *hirsutum*.

Other Pests. Regarding the other pests of cotton in India, no success seems to have been achieved in the development of resistant vairieties. In *desi* cottons in India, strains carrying the red body colour are reported to be definitely less palatable to bollworms (Christidis and Harrison, 1955). Also, there are several reports indicating that the indigenous cottons of India were less infested by pink bollworm than the imported *hirsutum* varieties (Fletcher, 1914, 1919 ; Marlatt, 1918 ; Husain, Afzal and Khan, 1940). The native Haitian cotton, *G. hirsutum* race *punctatum*, has been reported to show considerable resistance to pink bollworm (Wolcott, 1927, 1928). Deger (1936) reported from Guatemala the existence of a hybrid between perennial and annual Upland cotton that was resistant to pink bollworm as well as to boll weevil. Fenton (1928) reported that pink bollworm infested less than four per cent. of the bolls of the diploid wild species, *G. thurberi*, from Arizona while cultivated cotton had about 100 per cent. infestation. This species has been utilised in breeding by Anson *et al.* (1945) and Knight (1944a, 1946b, 1947a). At Indore, however, the sterile F_1 hybrid between this species and *arboreum* as also the colchicine induced fertile amphiploid, were attacked by pink bollworm. No risistant segregates were obtained from backcrosses of the amphiploid to *hirsutum* or *barbadense*(Ganesan, 1947). Anson *et al.* (1948) reported that *G. somalense* also showed marked resistance to pink bollworm and also that *G. armourianum*, *G. somalense*, *G. thurberi* and *G. raimondii* were resistant to *Earias insulana* Boisd. Breeding for resistance to the latter insect, using some of the above mentioned species was reported to be under way in the Sudan. Cheo (1943), in his studies on the cotton leaf roller (*Sylepta derogata* Fabr.), found that cotton varieties with divided leaves had about nine per cent. of the plants with one half or more of the leaves rolled by this insect, while varieties with undivided leaves had 95 per cent. of the plants with one half or more of the leaves rolled (see also Ma, 1945). The cotton stem weevil (*Pempherulus affinis* Fst.) causes considerable damage particularly to the young plants, in Madras State and other areas of India. According to Ballard (1923) some strains of Cambodia *hirsutum* are less liable to attack when they are young, than are other strains. *Gossypium arboreum* race *indicum* was reported to be less injured than *G. herbaceum*. Dharmarajulu *et al.* (1934) reported that selection and isolation of resistant

and tolerant strains was being done. Dharmarajulu (1936) and Balasubrahmanyan (1950) have stated that the mechanism of resistance shown towards stem weevil by some South American perennial cottons such as Moco, Quebradinho and Verdao, consists in the fact that the attacking grub of the stem weevil is killed as a result of gall formation and production of callus tissue in the host plant ; the gum formed by the breakdown of the callus tissue flowing into the burrows of the larvae and killing them.

CORRELATION

Different characters of a plant are often correlated with each other. This may either be due to pleiotropy, i.e., manifold effects of a gene or genes on different parts of the plant, or due to genetic linkage (Harland, 1939). The former type of correlation belongs to the category of physiological association which information is valuable as it indicates that it is not possible to separate, by breeding, the characters so associated. If the correlation is due to genetic linkage, it is possible to reverse the correlation, if so desired, unless the linkage is very close. It is, therefore, important to establish the genetic basis of correlations observed in plant breeding work. It may be mentioned here that a large majority of correlation studies have been conducted on varieties and only a few on segregating progenies from hybrids ; the latter gives an indication of the extent to which genetic linkage is responsible for the correlation observed. Correlation studies are an important asset to the breeder of any crop; they are all the more important in the case of a quality crop like cotton in which it is necessary to determine the relationship between yield and quality or between the various factors contributing to quality. A number of characters, which are less variable and less complicated in inheritance than yield, are so closely connected with yield and quality that attention should be focussed on plants possessing them. In spite of the impossibility of fully analysing yield genetically, substantial progress in breeding for high yield and quality may yet be made by determining experimentally the final yield and other characters known to affect it. It also happens that, due to character correlations, improvement in respect of one character may have been obtained at the expense of another. Thus increase in yield or ginning percentage may result in the reduction of staple length, and *vice versa*.

Table 28 shows the nature of association observed by various workers between the different economic characters in cotton.

Association Between Qualitative And Quantitative Characters. The study of this type of association is helpful to the breeders as it makes available to them an easy index to work with. It is, however, important to test the universality of such correlations through studies on several hybrid progenies.

Hutchinson (1934) made several interspecific and intervarietal crosses in the Old World cottons so as to study the inheritance of leaf shape and its rela-

tionship with other economic characters, such as ginning percentage, lint length, and lint index. He discovered the existence of linkage between the allelic series for leaf shape and some of the genes affecting lint length, seed weight and ginning percentage. Broad-leaved types have on the whole, longer and finer lint than narrow-leaved plants and generally have a lower ginning percentage. Crosses between *G. arboreum* and *G. herbaceum* indicated that the latter species carries a gene for long lint in the same chromosome which carries the leaf shape genes ; the same gene for lint length, carried by *G. herbaceum*, also increased the weight of seed. Hutchinson and Ghose (1937a) stated that there is no necessary association between morphological and agricultural characters, but that factors affecting lint length and lint index exist in the leaf shape chromosome. Thadani (1938), studying pure *cutchicum* and *roseum* (*G. arboreum*) white-flowered types, observed that broad-leaved *cutchicum* types had definitely higher ginning percentage and rougher feel than narrow-lobed *roseum* type, but they were not so high yielding as were the *roseum* types. Rana (1952—Unpubl.), however, found in his studies on a number of intervarietal crosses in *G. arboreum* that high yield was associated with broad leaf, while higher ginning percentage and longer staple go with narrow leaf. Ramiah and Bholanath (1947) observed that in several *arboreum* crosses all narrow-leaved plants had long bolls.

As regards flower colour, Kearney (1923a) found corolla colour to be positively correlated with lint length in F_2 of Upland x Egyptian crosses ; Burd (1926), however, found no difference in intra-*barbadense* hybrid material between the means of yellow and white classes, in respect of lint length. Harland (1939) observed that the gene $\mathbf{Y_b}$ in *G. barbadense* was associated with a slightly longer lint than the recessive (**y**). In Old World cottons, yellow-flowered plants are reported to have a slightly longer lint than white-flowered plants (Afzal, 1930; Hutchinson, 1931) ; the former author found petal length to be positively correlated with lint length as also with yellow flower colour. Hutchinson, (1931) observed that lint index was about six per cent. greater in white-flowered segregates than in the yellow-flowered ones. Hutchinson and Ghose (1937a) reported that a factor affecting yield, in the Malwa tract, exists in the corolla colour chromosome; yellow-flowered types gave in this tract more yield than white-flowered and had longer and finer lint, but lower ginning outturn. Under the Punjab conditions, however, white-flowered segregates, from white-flowered x yellow-flowered crosses in *G. arboreum* were invariably higher yielding, although one significant exception was also noticed ; flower colour did not show any significant association with ginning percentage or lint length (Rana, 1952 — Unpubl.).

Neely (1943) observed that green lint and low lint index are associated in *G. hirsutum*. In Uplands (*hirsutum*) and Sea Island (*barbadense*), naked seed is completely linked with low amount of lint per seed (Griffee and Ligon, 1929 ; Thadani, 1923 ; Ware, Jenkins and Harrel, 1944 ; Richmond, 1949).

TABLE 28. CORRELATION OF CHARACTERS IN COTTON

Pairs of characters	Correlation (r)		Material	Authors
A. a. YIELD OF SEED COTTON and				
1. Number of bolls per plant	+0·94	*arboreum*	Between intervarietal hybrid progenies	Rana, 1952-Unpubl.
2. ,, ,,	High positive	*hirsutum*		Stroman, 1930
3. Weight of bolls	+0·41	*arboreum*	,,	Rana, 1952-Unpubl.
4. ,,	High positive	*hirsutum*		Stroman, 1930
5. Proportion of 5-lock bolls	Positive	,,	Texas varieties	Stroman, 1925
6. Number of flowers per plant	No relationship	,,	Varietal trials in the Punjab	Afzal, 1941
7. ,,	High positive	*barbadense*		Balls and Halton, 1915: Crowther, 1941
8. Number of monopodia	+0·57 ±0·02	*arboreum*	Northerns–within a strain	Venkataraman and Jagannatha Rao, 1933
9. ,,	+0·65 ±0·06	,,	Northerns–between strains	,,
10. ,,	−0·46 ±0·12	*hirsutum*	Varietal tests in the U.S.A.	Griffee *et al.*, 1929
11. Ginning percentage	+0·52 ±0·11	,,	,,	,,
12. Lint yield	+0·86 ±0·04	,,	,,	,,
13. Fibre length	Generally negative	*arboreum* & *herbaceum*	Intervarietal hybrids	Ramanathan, 1938
14. ,,	Non-significant	*arboreum*	Between intervarietal hybrid progenies	Rana, 1952-Unpubl.
15. ,,	−0·46 ±0·12	*hirsutum*	Varietal tests in the U.S.A.	Griffee *et al.*, 1929
16. Height of plant	+0·53 ±0·02	*arboreum*	Northerns–within a strain	Venkataraman and Jagannatha Rao, 1933
17. ,,	+0·18 ±0·10	,,	Northerns–between strains	,,
18. ,,	Negative	*hirsutum*		Stroman, 1930
19. Length of stem internode	−0·57 ±0·10	,,	Varietal tests in the U.S.A.	Griffee *et al.*, 1929
20. Area of largest leaf	−0·38 ±0·13	,,	,,	,,
21. Width of leaf (mid-lobe)	Negative	*arboreum*	Types	Thadani, 1938
22. ,,	Positive	,,	Intervarietal hybrid	Rana, 1952-Unpubl.
23. Petal colour (White→Yellow)	,,	,,	,,	Hutchinson and Ghose, 1937a
24. ,,	Negative with one exception	,, ,,	,,	Rana, 1952-Unpubl.

b. YIELD OF LINT and				
25. Lint index	$+0 \cdot 75$; $+0 \cdot 56$	*barbadense*	Sea Island (2 years)	Harland, 1919
26. Lint per boll	$+0 \cdot 54$; $+0 \cdot 84$	,,	,,	,,
B. GINNING PERCENTAGE and				
1. Fibre length	Non-significant to negative	*arboreum*, *herbaceum* & *hirsutum*	Intervarietal hybrid	Patel and Patel, 1927: Sikka and Afzal, 1947: Rana, 1952-Unpubl.
2. ,,	Non-significant to highly negative	*hirsutum*	Varieties	Humphrey, 1940
3. ,,	Negative			Duggar, 1911
4. ,,	$-0 \cdot 24 \pm 0 \cdot 07$	,,	Shorter staple types, Arkansas, U.S.A.	Hodson, 1920
5. ,,	$-0 \cdot 61 \pm 0 \cdot 04$	,,	Both shorter and longer staple types considered together, Arkansas, U.S.A.	,,
6. ,,	$-0 \cdot 45 \pm 0 \cdot 042$	,,	Single plant selections in Texas cotton	Dunlavy, 1923
7. ,,	Negative	,,	Texas cotton	Killough and Hafner, 1927
8. ,,	$-0 \cdot 46 \pm 0 \cdot 12$	,,	Varietal tests, U.S.A.	Griffee *et al.*, 1929
9. ,,	Non-significant to $-0 \cdot 18$	,,	Successive selection progenies from local and intervarietal hybrid material	Stroman, 1949
10. ,,	$-0 \cdot 45$ to $-0 \cdot 83$	,,	Between varieties	Christidis and Harrison, 1955
11. ,,	Non-significant	*barbadense*	Egyptian cotton	Brown, 1935
12. Lint index	$+0 \cdot 64$	*arboreum*	Between intervarietal hybrid progenies	Rana, 1952-Unpubl.
13. ,,	$+0 \cdot 20 \pm 0 \cdot 050$	*hirsutum*	Single plant selections in Texas cotton	Dunlavy, 1923
14. ,,	$+0 \cdot 38$ to $+0 \cdot 76$	,,	Successive selection progenies from local and intervarietal hybrid material	Stroman, 1949
15. ,,	$+0 \cdot 54$	*barbadense*	Pima	Kearney, 1926
16. Seed weight	$-0 \cdot 95$	*arboreum*, *herbaceum* & *hirsutum*	In India	Turner, 1929

TABLE 28. CORRELATION OF CHARACTERS IN COTTON—*Contd.*

Pairs of characters	Correlation (r)		Material	Authors
17. Seed weight	−0·40 ±0·08	*hirsutum*	Types, Arkansas, U.S.A.	Hodson, 1920
18. ,,	−0·53 ±0·04	,,	Single plant selections in Texas cotton	Dunlavy, 1923
19. ,,	−0·43	*barbadense*	Pima	Kearney, 1926
20. ,,	−0·88	,,	Egyptian cotton	Turner, 1929: (also see Brown, 1935)
21. Fibre weight	Positive trend	*arboreum*	Intervarietal hybrid	Sikka and Afzal, 1947
22. ,,	−0·21 to −0·37	*hirsutum*	Successive selection progenies from local and intervarietal hybrid material	Stroman, 1949
23. Swollen hair diameter	Non-significant to +0·22	,,	,,	,,
24. Boll size	−0·39 ±0·05	,,	Single plant selections in Texas cotton	Dunlavy, 1923
25. Boll weight	+0·26 to +0·60	,,	Successive selection progenies from local and intervarietal hybrid material	Stroman, 1949
26. Seed cotton weight per boll	+0·24	*barbadense*	Pima	Kearney, 1926
27. Lint weight per boll	+0·60	,,	,,	,,
28. Boll length	+0·18	,,	,,	,,
29. Boll diameter	+0·07	,,	,,	,,
30. Percentage of 5-lock bolls	+0·04 ±0·06	*hirsutum*	Single plant selections in Texas cotton	Dunlavy, 1923
31. Number of seeds per lock	+0·10 ±0·06	,,	,,	,,
32. Number of seeds per boll	+0·28	*barbadense*	Pima	Kearney, 1926
33. Oil content	Negative			Christidis and Harrison, 1955
34. Width of leaf (mid-lobe)	Positive	*arboreum*	Types	Thadani, 1938
35. ,,	Negative	,,	Between intervarietal hybrid progencies	Rạna, 1952–Unpubl.
36. ,,	,,	*herbaceum* & *arboreum*	Intra and interspecific hybrid material	Hutchinson, 1934
37. Petal colour (White→Yellow)	,,	*arboreum*	Intervarietal hybrid material	Hutchinson and Ghose, 1937a

C.	LINT INDEX and				
	1. Fibre length	+0·15 ±0·05	*hirsutum*	Single plant selections in Texas cotton	Dunlavy, 1923
	2. ,,	Non-significant	,,	Successive selection progenies from local and intervarietal hybrid material, New Mexico, U.S.A.	Stroman, 1949
	3. Fibre strength	−0·11 to +0·17	,,	,,	,,
	4. Swollen hair diameter	+0·17 to +0·32	,,	,,	,,
	5. Seed weight	High positive	*herbaceum*		M. L. Patel, 1922: Patel and Mankad, 1926
	6. ,,	,,	*hirsutum*		Afzal, 1930
	7. ,,	+0·70 ±0·02	,,	Single plant selections in Texas cotton	Dunlavy, 1923
	8. Weight per seed	+0·38	*barbadense*	Pima	Kearney, 1926
	9. Presence of seed fuzz	Positive	*hirsutum*	Intervarietal hybrid	Thadani, 1923: Griffee and Ligon, 1929: Ware, 1940: Richmond, 1949
	10. ,,	,,	*barbadense*	Types	Ware, Jenkins and Harrel, 1944
	11. Boll size	+0·48 ±0·05	*hirsutum*	Single plant selections in Texas cotton	Dunlavy, 1923
	12. Boll weight	+0·34 to +0·73	,,	Successive selection progenies from local and intervarietal hybrid material, New Mexico, U.S.A.	Stroman, 1949
	13. Lint weight per boll	+0·90	*barbadense*	Sea Island	Harland, 1919
	14. ,,	+0·54	,,	Pima	Kearney, 1926
	15. Seed cotton weight per boll	+0·35	,,	,,	,,
	16. Boll length	+0·24	,,	,,	,,
	17. Boll diameter	+0·23	,,	,,	,,
	18. ,,	+0·21	*hirsutum* & *barbadense*	Hybrid	Kearney, 1923
	19. Percentage of 5-lock bolls	+0·08 ±0·06	*hirsutum*	Single plant selections in Texas cotton	Dunlavy, 1923
	20. Number of seeds per lock	−0·08 ±0·06	,,	,,	,,
	21. Number of seeds per boll	−0·07	*barbadense*	Pima	Kearney, 1926
	22. Lint colour (White→Green)	Negative	*hirsutum*	Between varieties	Neely, 1943
	23. Petal colour (White→Yellow)	Slightly negative	*arboreum* & *herbaceum*	Intervarietal hybrid	Hutchinson, 1931

TABLE 28. CORRELATION OF CHARACTERS IN COTTON—*Contd.*

Pairs of characters	Correlation (r)	Material		Authors
D. FIBRE LENGTH and				
1. Fibre fineness	Positive	*arboreum*	Intervarietal hybrid	Sikka and Afzal 1947: Panse, 1946:
2. ,,	Non-significant	*arboreum & herbaceum*	Types in India	Christidis and Harrison, 1955
3. ,,	Positive	*hirsutum*	,,	,,
4. Fibre strength	−0·15 to −0·30			Nanjundayya and Ahmad, 1938
5. ,,	+0·15 to +0·27	,,	Successive selection progenies from local and intervarietal hybrid material	Stroman, 1949
6. Swollen hair diameter	Non-significant to −0·18	,,	,,	,,
7. Spinnability	Positive		Indian cotton	Iyengar and Turner, 1930
8. Yarn strength	+0·87			Turner and Venkataraman, 1933
9. ,,	+0·77	*barbadense*	Egyptian cotton	Underwood, 1935
10. Boll size	+0·21 ±0·06	*hirsutum*	Single plant selections from Texas cotton	Dunlavy, 1923
11. Boll length	+0·18	*hirsutum & barbadense*	Hybrid	Kearney, 1923
12. Percentage of 5-lock bolls	−0·11 ±0·06	*hirsutum*	Single plant selections from Texas cotton	Dunlavy, 1923
13. Number of seeds per lock	−0·16 ±0·06	,,	,,	,,
14. Strength of attachment of fibres to seed	−0·64			Christidis and Harrison, 1955
15. Lint colour	−0·23	*hirsutum* (Holdon)–*barbadense* (Pima)	Hybrid	Kearney, 1923
16. Seed weight	+0·43 ±0·04	*hirsutum*	Single plant selections from Texas cotton	Dunlavy, 1923
17. Oil content	Positive			Christidis and Harrison, 1955
18. Petal colour (White→Yellow)	Slightly positive	*herbaceum & arboreum*	Intervarietal hybrid	Afzal, 1930: Hutchinson, 1931: Hutchinson and Ghose, 1937a
19. ,,	Non-significant	*barbadense*	,,	Burd, 1926

	20. Petal colour (White→Yellow)	Slightly positive	*barbadense*		Harland, 1939
	21. ,,	+0·28	*hirsutum* & *barbadense*	Hybrid	Kearney, 1923
	22. Petal length	Positive			Afzal, 1930
	23. Stigma length	Very slight, if any	*hirsutum* & *barbadense*	Hybrid	Kulkarni and Khadilkar, 1929
	24. Width of leaf (mid-lobe)	Generally positive	*arboreum* & *herbaceum*	Intra and interspecific hybrid	Hutchinson, 1934
	25. ,,	Negative	*arboreum*	Intervarietal hybrid	Rana, 1952-Unpubl.
E.	FIBRE WEIGHT and				
	1. Spinnability	−0·60			Hutchinson and Govande, 1938
	2.	Negative	*arboreum*, *herbaceum* & *hirsutum*	In India	Iyengar and Turner, 1930
	3. Fibre strength	+0·74 to +0·84			Nanjundayya and Ahmad, 1938
	4. Percentage of mature fibres	+0·59			Gulati and Ahmad, 1935
	5. Swollen hair diameter	+0·75			Koshal and Ahmad, 1939
	FIBRE FINENESS and				
	6. Petal colour (White→Yellow)	Positive			Hutchinson and Ghose, 1937a
	7. Width of leaf (mid-lobe)	,,	*arboreum* & *herbaceum*	Intra and interspecific hybrids	Hutchinson, 1934
	8. ,,	Negative	*arboreum*	Types	Thadani, 1938
F.	FIBRE STRENGTH and				
	1. Percentage of mature fibres	+0·72			Gulati and Ahmad, 1935
	2. Swollen hair diameter	−0·31 to +0·45	*hirsutum*	Successive selection progenies from local and intervarietal hybrid material	Stroman, 1949
	3. Spinnability	Negative	*arboreum*, *herbaceum* & *hirsutum*	In India	Gadkari, 1956
	4. Yarn strength	−0·41 to −0·61			Barrett, 1929
G.	FIBRE MATURITY and				
	1. Spinnability	Negative		Short staple cottons of India	Gulati and Ahmad, 1935
	2. ,,	+0·56		Medium staple cottons of India	,,
	FIBRE IMMATURITY and				
	3. Neps	+0·81			,,
H.	SWOLLEN HAIR DIAMETER and				
	1. Spinnability	−0·58			Hutchinson and Govande, 1938
	2. ,,	−0·80			Koshal and Ahmad, 1939

Association Between Quantitative Characters. This is discussed below under different heads.

(*i*) *Yield:* The number of bolls per plant had been found, by numerous workers to bear by far the closest relation to yield and for the same number of bolls produced per plant, final yield is directly proportional to boll weight. According to Stroman (1930) boll weight is negatively related to boll number per plant in *hirsutum*. On the other hand Rana (1952 Unpubl.) in his studies on intervarietal hybrids of *arboreum* discovered neither physiological nor genetic correlation between the two characters. According to Balls and Halton (1915) yield is primarily dependent upon the number of flowers per plant. Crowther (1941) also considered the cumulative flower number to be highly correlated with yield. Harland (1918) believed that for comparison of different varieties for yielding capacity, both flowering and bolling records are almost essential. Afzal (1941), however, failed to obtain relationship between flower production and yield, which is not unexpected in view of the fact that shedding, so common during the warmer period, is responsible for reducing the number of bolls per plant.

Griffee, Ligon and Brannon (1929) reported that yield of seed cotton is negatively correlated with the length of stem internode, area of the largest leaf, number of vegetative branches and lint length, but it was positively correlated with ginning percentage and yield of lint. Killough and Hafner (1927) and Ramanatha Ayyar (1938a) also reported that yield of seed cotton or of lint, was negatively correlated with lint length and that the improvement in lint length is, therefore, often likely to be attended with reduction in yield. Venkataraman and Jagannatha Rao (1933) reported the number of monopodia to be positively correlated with yield within and between strains of Northerns, the *arboreum* material studied by them, but plant height was markedly and positively correlated with yield only within a strain. Selection for productivity on the basis of number of monopodia per plant is, therefore, considered justifiable by the authors in cottons of monopoidal habit like the Northerns.

(*ii*) *Earliness :* The relationship between earliness on the one hand and yield and quality on the other is often close (Brown, 1951) as earliness also usually helps in reducing damage by insect pests and, in some parts of the world, by cold weather. Within a variety, earliness and yield are negatively correlated whereas between varieties this correlation is positive (Christidis and Harrison, 1955; Franquin, 1954). Duggar (1911) found earliness opposed to large boll size. Date of maturity is positively correlated with date of flowering and bolling period (Christidis and Harrison, 1955). Hutchinson, Gadkari and Ansari (1938) reported that the time of maturity was closely correlated with the size and bushiness of plants.

(*iii*) *Ginning Percentage and Lint Index :* Yield and ginning percentage have been reported to be positively correlated. Similar is the correlation between

ginning percentage on the one hand and lint index, boll weight and number of loculi per boll on the other. Dunlavy (1923), however, reported that ginning outturn was negatively correlated with boll size. The relationship of ginning percentage with lint length and weight of seed has been found to be negative (Duggar, 1911 ; Hodson, 1920 ; Dunlavy, 1923 ; Ramanatha Ayyar, 1938a). In a cross between the commercial Upland (*hirsutum*) cotton Acala and the wild variety Hopi, unfavourable association of ginning percentage with other fibre properties was reported by Stith (1956). On the basis of phenotypic and genetypic correlations in the F_2 and F_3 of the cross, Stith (*loc. cit.*) concluded that selection for large boll size would result in longer, stronger and finer fibres but low lint percentage. Antagonistic relationship between lint length and ginning percentage has also been reported for all the varieties produced or tried in Greece during the past 10 years (Christidis and Harrison, 1955). Since this resulted, in spite of the fact that every effort was all along made to achieve the opposite, antagonism of the two characters was considered quite plausible. In India, Patel and Patel (1927) reported a slight negative correlation between ginning outturn and staple length in one of the two hybrid progenies of *herbaceum* they studied. Brown (1935), however, reported no correlation between these characters. Sikka and Afzal (1947) and Kelkar and Kaiwar (1947) observed in hybrid progenies of *arboreum* and *hirsutum*, respectively, that although there was a general trend for high ginning to be associated with reduced lint length, the possibility of combining the two characters cannot be excluded.

Naked (Fuzzless) seed is completely linked with low lint index in Upland (*hirsutum*) cotton (Ware, 1940 ; Richmond, 1949) and also in Sea Island (*barbadense*) cotton (Ware *et al.*, 1944). Nevertheless, Ware (1940) suggested that it may be possible to breed varieties combining high lint index with sparse fuzz. An increase in fibre population per seed, which should be conducive to increase in ginning outturn, has been found to be associated with decreasing fibre weight and fibre strength and with increasing percentage of thin-walled fibres (Christidis and Harrison, 1955).

(*iv*) *Lint Length:* This character has been observed to be negatively correlated with yield of seed cotton or of lint and with ginning percentage, as has been mentioned earlier, but positively correlated with weight of seed (Kelkar *et al.*, 1947a), boll length and boll size (Christidis and Harrison, 1955). Some authors found boll weight to be negatively correlated with staple length. It also appears (Rana, 1952-Unpubl.) that although staple length and ginning outturn are negatively correlated in *arboreum* this relationship is often not significant statistically and that, therefore, it is possible to combine high yield with good ginning percentage and lint length.

Ram Prasad (1922), studying populations obtained by vicinism between long and short stapled varieties of *arboreum*, noticed that there probably existed a positive relationship between stigma length and staple length. Kulkarni

and Khadilkar (1929) investigated the possibility of existence of a similar relationship in *hirsutum* (Gadag 1)—*barbadense* (Sea Island) hybrid material by correlation studies. They concluded that such a relationship is, at most, a very slight one and, therefore, no practical use in selection or roguing of cotton for good staple types.

Hawkins (1938) observed that the longest and the shortest fibres are less mature than fibres of an intermediate length. In selecting progenies for a more uniform length, the plant breeder would also be selecting towards improved fibre maturity.

(*v*) *Lint Fineness:* According to Iyengar and Turner (1930), the Old World cottons do not show much improvement in fineness with increase in lint length, whereas in American cottons, types with longer fibres generally possess less fibre weight per inch. Sikka and Afzal (1947) and Panse (1947), however, found staple length and fineness to be positively correlated in some *arboreum* crosses. According to Stroman (1942) swollen hair diameter decreases as hair length increases in *hirsutum*. Sikka and Afzal (1947) observed a tendency for fibre weight to increase with ginning percentage. Brown (1935) found hair weight per centimeter to be highly correlated with seed weight in Giza 19 and some other *barbadense* cottons. Regnery (1952) reported that fineness is associated with neppiness.

(*vi*) *Lint Strength :* Hair strength appears often to be positively correlated with fibre weight (Christidis and Harrison, 1955). Meredith (1951) observed that this character was associated with X-ray angle of molecular orientation of the crystallites but this association was not high enough to allow prediction of strength from X-ray orientation.

(*vii*) *Oil Content :* Some early evidence points to a positive correlation between oil content and lint length, but oil content and ginning percentage or seed weight are often negatively correlated (Christidis and Harrison, 1955). Naked varieties possess increased oil content as compared to fuzzy-seeded ones.

(*viii*) *Spinning Performance:* Iyengar and Turner (1930) found spinning performance to be positively correlated with mean fibre length whereas its relationship with mean fibre weight per inch, fibre strength and mean fibre width was negative. Gulati and Ahmad (1935) studied 32 Indian cottons and observed that for comparatively short staple varieties, high spinning performance was associated with lower fibre maturity, whereas for medium staple varieties high spinning was associated with high fibre maturity.

It will be seen from the foregoing account that there is extensive literature on character correlation studies in the different species of cotton, a majority of which have been conducted within (intra-varietal correlation) and between (inter-varietal correlation) varieties and some on segregating hybrid progenies. The primary object of all such work has been to determine the rela-

tionship between character pairs and to assess the scope of combining them in desirable expressions. Because, if a desirable character is associated with an undesirable one, selection for one without the other is difficult. This presents a problem to the breeder.

Regarding characters of primary importance to the cotton breeder, it has appeared that yield is strongly influenced by boll number per plant and boll weight ; ginning percentage is positively correlated with yield, but there is a marked tendency towards fibre length being unfavourably associated with both yield and ginning percentage; and increasing fibre length or fineness is associated with neppiness. These are general relationships and where unfavourable association between desirable characters is indicated, there is evidence suggesting that it is not absolute, as was pointed in the case of ginning percentage and fibre length by Sikka and Afzal (1947) and Kelkar and Kaiwar (1947). Again, Rana (1952-Unpubl.) actually obtained a positive correlation ($r = +0{\cdot}31^*$) between yield and staple length in one out of the 28 cross combinations studied by him. In the other 27 crosses the r value ranges between $-0{\cdot}04$ and $-0{\cdot}44^{**}$ (one and two asterisks signifying statistical significance at 5 and 1 per cent. levels, respectively) ; only in five crosses the negative correlation was statistically significant. There is thus reason to believe that in some material at least it is possible to obtain favourable expressions of such characters.

Stroman (1949) studied a number of character correlations in genetically segregating *hirsutum* material and observed that the correlations were not always consistent from one year to another. He suggested that each of these characters may be the result of the expression of several genes. Significant correlations between characters may be caused by multiple factors, some of which may influence both characters in combination with other genes (pleiotropy or gene interaction). Also, one or more of the genes involved in the expression of one character might be linked with one or more of the genes which cause the expression of the other character. In such cases, although a frequent negative relationship may indicate that the genes affecting the particular character pair are closely linked in the repulsion phase, even a single positive (significant) correlation value would suggest that there is a chance for the linkage being broken and for the gene combination changing to the coupling phase.

DISCRIMINANT FUNCTION

Yield and quality in cotton, in common with other plants, are complex characters stemming from the integration of a number of component characters, all of which are subject to large environmental fluctuation. The performance of an individual plant is consquently not a reliable index of the genotype. In extreme cases, where selected plants show high yields due to a favourable environment, a negative correlation may be found between the yield of the parent plants and their progenies. This makes single

plant selection the weakest link in the chain of plant breeding procedure and any practical device that can be developed to make it more effective may be expected to raise the efficiency of selection. Fisher's discriminant function which is of the nature of an index, was applied to wheat by Smith (1936) and it involves the use of the least variable component of yield as the basis of selection. Hazel and Lush (1942) have indicated that when several traits affect the net worth of an organism, it is necessary to weigh variations in those characteristics in the proper ratio if maximum progress from selection is to be obtained. A method for estimating optimum relative weights has been given by Smith (1936), Hazel (1943) and Lerner *et al.* (1947) for various selection projects. Robinson *et al.* (1951) have given procedures for estimating genotypic and phenotypic covariances required for the construction of a selection index.

The yield of seed cotton per plant may be considered as the product of three factors ; number of bolls on the plant, number of seeds per boll and the weight of seed cotton per seed ; the yield of lint may similarly be expressed by multiplying this product with the ginning percentage and dividing by 100. Panse and Khargonkar (1949) set up a discriminant function for selection of yield in cotton (*G. arboreum*), using the above traits and analysing, for this purpose, the results from two varietal trials and two progeny row trials. Calculation of the genetic advance due to the use of the discriminant formula compared to straightforward selection for plant yield was made ; but it was found that the discriminant formula gave very little extra improvement as compared to simple selection on yield. They, therefore, concluded that the discriminant function, as studied by them, did not provide a method for making more efficient selection for yield than the plant yield itself.

Manning (1956) used a selection index technique with a continuously self-fertilised variety, B.P. 52 of *hirsutum* cotton, in which he considered three components of yield, viz., bolls per plant, seeds per boll and lint per seed, and obtained a total yield improvement of about 30 per cent. after six generations of selection. It was, however, observed that, in view of the manner in which measurements were made, yield was not completely specified by the data for the three fundamental yield components studied by him. Smith (1936) pointed out that when yield is completely determined by two or more component traits, all available information can be incorporated in the index in terms of either the full set of component traits or by substitution of yield for any one of them. Considering this point, Manning (1956) suggests the use of a selection index based on seeds per boll, lint per seed (Lint Index) and lint yield in cotton improvement programmes. Fryxel (1956) studied the *hirsutum* varieties, Hartsville and Acala, and an F_2 population derived from a cross between them from the standpoint of selection for yield. Data were collected on 13 variables obtained by sub-dividing yield into component

traits and the vaious traits were then used to construct 14 selection indices. The indices tended to be more efficient criteria of selection than yield itself, having a mean efficiency of 250 per cent. compared with direct selection for yield. The heritabilities of the component traits generally showed a progressive increase with successive levels of sub-division, in agreement with the assumption that yield is controlled by additive genes.

The plant breeder is always concerned with two factors, the variability of the many characters with which he is working and the correlation between these characters. The latter factor, in relation to cotton has been discussed above. As regards the former, it is important that the breeder's material must vary enough to include at least the potentialities for all the desired characters as well as all other favourable characters of yield and quality. For this, he has to look for natural sources of variability and also to artificially create further variability by methods like hybridisation, and induced mutations and polyploidy. Such variable material constitutes the basis on which plant breeders base their selection programmes by using different techniques of selection. These methods and techniques, as used in cotton breeding, are discussed in the following section.

BREEDING METHODS

The object of breeding in any economic plant is the production of new varieties, which under certain conditions of soil and climate prevailing in a tract, would give higher yields and better quality produce as compared to the existing types. In cotton, yield is almost as important as quality. A consideration of inter-relationships between diverse factors contributing to yield and quality in this crop has shown the existence of favourable as well as opposing trends. A cotton breeder has, therefore, to aim at the happiest available combinations of the desirable traits. In this crop, more than any other success in breeding is achievable through several smaller steps than through a few phenomenal ones. In the initial stages of breeding, progress is of course quicker and tangible. Later, every smaller advance made is worth the attempt.

All plant breeding is a vast experiment in selection. Selection may be practised in naturally varying local or introduced populations, where the amount of variability would largely depend upon the extent of natural outcrossing and on the rate of spontaneous mutation. It may also be practised in artificially raised hybrid progenies or in material subjected to mutagenic agencies for accelerating mutation rate. To a breeder, genetic variability is important, and not the non-heritable fluctuations caused by environmental factors. Whichever among the several selection techniques is adopted by the breeder, it is incumbent on him to assess the genetic component of variability, as distinct from the environmental, and to estimate the genetic advance achieved as a result of selection work. In other words, the breeders' selections

should be based on the genotype rather than on mere phenotypic appearance. The merit of a selection is evaluated on the performance of its progeny through statistically designed field tests.

Selection can be practised with or without inbreeding. The effect of close inbreeding, which is often adopted in plant breeding for securing a high degree of uniformity at a high level in respect of yield and quality, is to narrow down greatly the genetic make-up of the selected populations or strains. Repeated inbreeding results in too much homozygosity which often adversely affects the vigour, productivity and adaptability of a strain to varied environmental conditions. The breeder's objective is to evolve genetically plastic improved strains which would be adapted to as wide a range of soil and climatic conditions as possible. To this end he may even seek to develop judicious mixtures of genotypes by bulking together a number of lines of comparable performance.

Hybridisation, apart from mutation, is perhaps the most powerful tool in the hands of a breeder for the creation of new forms. Even the immediate product of hybridisation namely the F_1 hybrid may be capable of commercial exploitation on account of its vigour and productivity. Again, through the attendant phenomena of gene segregation and recombination, hybridisation triggers off an immense array of genetically variable forms. It has, therefore, been extensively exploited in plant breeding work for increasing variability and for combining good qualities of different strains through newer recombinations, or interactions, of existing genes. Selection in segregating hybrid progencies, by the adoption of appropriate techniques, has been effective, in cotton as in several other crops, in the evolution of newer and better strains. Hybridisation may be carried out within a species (intraspecific) or between species (interspecific). In the operation of a hybridisation project, considerations such as the choice of parents, and the manner of their utilisation in hybridisation, viz., single, three-way, double, multiple or backcress, are as important as those pertaining to selection techniques to be adopted. Interspecific hybridisation often creates problems, such as sterility and genetic erosion of the vitality complex (Harland, 1955), which have to be appropriately tackled.

The present section seeks to discuss these problems in relation to cotton breeding.

ACCLIMATISATION

The introduction of new types constitutes the easiest and most rapid method of crop improvement ; it is usually resorted to before any kind of proper breeding work is initiated. The history of *G. hirsutum* in India is a striking example of successful introduction and acclimatisation. *Gossypium barbadense* has not faired well at all in this country ; only in recent years some amount of success appears to have been obtained in its commercial cultivation in the

States of Kerala and Mysore. Other examples include the introduction of Egyptian varieties (*barbadense*) into the irrigated valley of southern Arizona (U.S.A.) and into the U.S.S.R., especially in Azerbaijan, and of Upland *hirsutums* into the U.S.S.R., China, Korea and Africa (Christidis and Harrison, 1955).

The view has been expressed that acclimatisation is bound to be a failure with varieties like the present day American Uplands which in their evolutionary history have become profoundly modified and adapted to particular conditions. Almost all successful New World types in Africa and India are descended from introductions made before the American varieties were stabilised and purified when their genetic variance was sufficiently great to allow of very considerable adaptive changes (Hutchinson, Gadkari and Ansari, 1938). Modern genetics has shown the importance of genetic variance in successful acclimatisation (Harland, 1932a). A variety introduced into a new locality, may respond differently to the new environment. Much of this, usually termed as 'new place effect', is change by selection in residual variance present in what may have appeared to be a 'pure' strain (Hutchinson *et al.*, *loc. cit.*). The residual variance is ascribed to heterozygosis in factors of no selection value in the environment from which the strain was brought. Student (1934) believes that types having residual variance may be changed very considerably by selection during acclimatisation in newer areas. It is, nevertheless, true that fresh introductions into new areas should consist of material possessing considerable genetic variability; such material may even include hybrids made with the definite object of providing a large amount of genetic variability.

GENETIC VARIABILITY

Under natural conditions, the two fundamental factors responsible for genetic variability are, no doubt, mutation and natural cross fertilisation; the former brings about change in the hereditary substance, whereas the latter causes recombinations and new interactions of already existing genetic factors. The extent of genetic variability in natural plant populations is predominantly influenced by the breeding system, apart from the natural rate of mutation, in the particular species to which the population belongs. Crossing (natural or, in the hands of the breeder, deliberate) increases genetic variability. Selfing or inbreeding leads, through homozygosis, to the establishment of a number of stable genotypes which in obligately autogamous species can subsequently be altered only through mutation. Even in self-pollinated species, an occasional natural cross may lead to new combinations of characters and thus be a source of material for selection. To a plant breeder, natural crossing can both be an asset and liability; while on the one hand the phenomenon can be useful in the production of genetic variability, on

the other it can create problems in the maintenance of purity of nucleus seed stocks of improved varieties.

The purity chequer and the replicated progeny row techniques adopted for assessing genetic variability are dealt with later in this section.

NATURAL CROSSING IN COTTON

Cotton is a predominantly self-fertilised crop, although considerable natural crossing has been reported to occur, depending largely on spacing, weather and variety (Zhubrin, 1930). Nagibin (1936) reported that vicinism was least in varieties with a spreading branching habit. There is evidence that some hereditary flower characters, such as increased pubescent area on both adjacent sides of petals, may lead to autogamy, so that these characters should, in breeding work, be taken into account. Moreover, if there are several minor genes for velocity of pollen tube growth, it should be possible to concentrate them in new types in which self pollen would grow so rapidly that crossing with foreign pollen would be practically impossible. Some incomplete evidence has been provided in this respect by Harland but the question needs further investigation (Christidis and Harrison, 1955).

Cross pollination in cotton appears to be entirely entomophilous as the amount of crossing depends mostly on the effective population of bees which act as pollen vectors (Balls, 1929; Stephens and Finkner, 1953; Thies, 1953; Finkner, 1954). According to Khan and Afzal (1950) the insects responsible are *Anthophora confusa*, *Apis dorsata* and *Elis thoracica*. In Egypt, Balls (1929) reported rapid diminution in vicinism from June to August owing to drop in bee population. He, therefore, advocated the keeping of late-picked cotton for maintenance of purity.

Natural crossing varying from less than one per cent. to eighty one per cent. has been reported by a large number of workers (Loden and Richmond, 1951); two to ten per cent. appears to be the usual range. In this work, marker genes responsible for red plant body or other distinguishing features have often been utilised. Simpson (1948) reported that at Knoxville, Tennessee (U.S.A.), natural crossing normally reaches 50 per cent. Jones and Loden (1951) stated that cotton is a largely self-fertilised plant, though there are certain sections of the cotton belt in the U.S.A. in which 30 to 50 per cent. cross-fertilisation occurs. Vysotskii (1930) observed 0·003 per cent. natural crossing in varieties belonging to different chromosome groups. Afzal and Khan (1950) reported about two per cent. out-crossing between contiguous rows of either *arboreum* or Upland cottons. According to these authors, natural crossing in Upland is very small beyond 12·5 feet; 100 feet giving perfect isolation. On the other hand Pope, Simpson and Duncan (1944) found that natural crossing occurred even up to 0·8 mile and recommended one mile or more of isolation. However, for practical purposes, the extent of isolation generally recommended is 100 yards (Brown, 1927),

40 feet (Collings and Wallace, 1931 ; Khan and Afzal, 1950), 40 meters (Fikry, 1931), 15 meters (Naghibin and Uzembaev, 1934). Trought (1930) emphasised the value of one variety communities for maintenance of crop purity as vicinism in this crop is high enough to be a serious detrimental factor in the propagation of pure strains. In Oklahoma (U.S.A.), the isolation problem for cotton in breeder's plots as well as on seed multiplication farms has been studied by Green and Jones (1953). They have recommended that 0 to 20 border rows should be discarded depending upon the size of the field (small to 20 acres or more) and the distance at which other cotton varieties are grown. Ordinarily, for plots less than 20 acres, the rows to be discarded are 10 to 15 in multiplication plots and 10 to 20 in breeder's plots.

TECHNIQUES OF SELFING AND HYBRIDISATION

The flower buds of cotton are large enough to be easily handled during selfing and crossing operations. Fertilisation takes place mostly in the morning of the day the flower opens and by the next day the corolla withers off and is shed away. Flower buds, which are expected to open the following day are selected for the purpose of selfing or emasculation prior to crossing; such flowers are easily recognised by their enlarged, yet un-open, corolla.

Selfing. The principle underlying the several methods of selfing advocated for cotton is to keep the petals closed during and after anthesis until the corolla drops away and the stigma is no longer receptive. The objective of all the methods is to make selfing operation quick, safe and inexpensive. The various ways in which this is achieved are : (*i*) to stitch the un-opened flower buds with needle and thread or merely to tie them by means of a strong wire, wool or a rubber band (Anon., 1929 ; Hilson and Parnell, 1917) ; (*ii*) to keep the petals closed by applying to the tip of the floral bud quick-drying gum (Knight, 1937), 1 gm : 2 c.c. shellac spirit solution (Low, 1955), potter's clay worked with water to a semi liquid consistency and reinforced with a few cotton fibres dipped in clay mixture (Ramanatha Ayyar, 1936) ; (*iii*) to slip a ring of copper wire on the tip of the flower bud, the ring being secured by means of a cotton thread fastened to the pedical (Kottur, 1918) ; (*iv*) to use a paper cone (Ballard, 1934) ; or (*v*) to cover the flower by means of netting and ½ lb. butter-paper bags (Anon., 1929 ; Kearney and Porter, 1926).

Hybridisation. With a suitable sharp scalpel, or the small blade of a knife the corolla of the flower bud is removed by giving a circular, shallow cut so that only the corolla is cut away without injuring the androecium and gynaecium within. All the anthers, and preferably the entire stamen tube is scraped off carefully without molesting the anthers or the style. The pistil with its stigma remains entirely intact. The emasculated flower is then covered with a paper bag until next morning, when it is pollinated with pollen from the desired parent and again covered with a paper bag and tag-labelled.

Doak (1934) developed methods for emasculating flowers by which corolla and androecium were removed in a single piece; for covering, the customary paper bag was substituted by a piece of soda straw wrapped at the base of the stigma with a wisp of lint (see also Beasley, 1934 ; Fielding, 1947). Humphrey and Tuller (1938) described a method in which emasculation and pollination take place in one operation, thereby saving extra labour. About one-fourth of the anthers of a bud from the male parent are scooped into a piece of soda straw which when slipped on to the pistil of the bud on the female parent removes upper anthers of the androecium and at the same time permits pollination of the stigma with pollen from the scooped anthers. The upper end of the straw is bent and the straw is fastened to the stem on which the flower is borne by means of a steel or a copper wire.

Lewis and Loden (1950) tried a number of methods of pollination in which the time of application of pollen was varied. They found that application of foreign pollen to the stigma of non-emasculated flowers before normal receptivity resulted in a significant increase in mean number of seeds per boll when compared with methods in which the pollen was applied at the time of anthesis; this increase was thought to be due to the stimulation of a substance or substances aiding fertilisation. Desai (1927) reported that the two most successful techniques employed by him in securing *herbaceum* x *hirsutum* crosses consisted in pollinating after painting the stigma with one and a half per cent. citric acid solution or with a mixture of one per cent. citric acid and half per cent. cane sugar solution. Other methods recommended in the case of distant crossing included the complete removal of perianth (Zaitzev, 1924), wiring and girdling the stem (Tanaka, 1937) and simultaneous selfing of some of the stigmatic lobes (Doak, 1937).

INBREEDING AND ITS EFFECTS

Inbreeding is commonly practised in crop improvement programmes for the attainment of homozygosity or near homozygosity, whereby true breeding, homogeneous populations of improved strains are built up. In cotton, divergent results have been reported in the literature regarding the ill effects, or otherwise, accruing from inbreeding. Harland (1923) expressed the view that inbred lines of Sea Island cotton are in no way distinguishable from commercial stocks except in a reduction of general vigour, which is usually slight and of little consequence to those engaged in cotton breeding. In fact, he found that selection of high lint index Sea Island cotton was effective even in material selfed for 17 generations (Harland, 1934a). In Greece also, 19 years of continued selfing did not result in the deterioration of productivity or of any other character (Christidis and Harrison, 1955). O'kelly (1942) and Anon. (1927) reported similar results. In India, Kottur (1921, 1928) and Jagannatha Rao (1931) did not notice any adverse effects of inbreeding

in *herbaceum* and *arboreum* cottons, respectively ; Kottur (1928) had subjected a pure line of *herbaceum* to inbreeding for 12 successive generations.

On the contrary, Leake and Ram Prasad (1912a) reported on the deleterious effects of inbreeding, such as contabascence of anthers and reduction of seed fertility ; these conclusions were, however, criticised by Harland (1923). Baltazar and Chakrabandhu (1940) compared plants from selfed and unselfed seed in some *barbadense* varieties and observed that plants from unselfed seed were more vigorous and yielded more. Similar results were reported by Krasovskii (1941). Brown (1942) studied the effect of inbreeding carried out over a 10-year period in Upland cotton and observed that while flowering rate, boll size and seed cotton production were reduced, respectively, by 6·2, 9·3 and 9·3 per cent., seed germination, vegetative growth, earliness, staple length, ginning outturn and seed weight were not appreciably affected. Simpson and Duncan (1953) also reported on reduced yields, to the extent of about 15 per cent., as a result of prolonged selfing. From these results, especially those reported by Simpson *et al.*, it would appear that the extent of crossing considerably influences the degree of inbreeding depression ; in areas of high natural crossing (Simpson, 1948), inbreeding is likely to produce deleterious effects. Richmond (1951) traced the development of methods of cotton breeding in the U.S.A. Early improvement was due to selection and propagation of apparently superior plants in the heterozygous varieties. Subsequently, as varieties seemed to lose yielding capacity, the question was debated as to desired closeness of selection and effects of inbreeding on varietal degeneration. Richmond suggested the following factors as contributory or related to reduction of productivity following inbreeding : (*i*) degree of heterogeneity of the original parent stock ; (*ii*) improbability of accumulating and holding all or most of the favourable yield genes in one homozygous line ; (*iii*) mechanical mixtures and cross pollinations with inferior varieties ; and (*iv*) selection for one or few characters without regard to other important characters in the genetic complex. The importance of the last concept was emphasised since too close a selection for one character has often resulted in inferiority for others and in too limited a gene base. In some instances, however, as in Pima and Montserrat varieties of *G. barbadense,* close selection has been practical (see also Harland, 1949).

Whatever the nature of effects of inbreeding, it is nevertheless true that a great homozygosity brought about by self-pollination may be suspected of leading to the production of strains of rather limited importance on account of their special adaptation to specific environmental conditions. In such cases, or if prolonged inbreeding resulted in somewhat reduced vigour or productivity, a mixture of seeds from several closely related selfed lines can be naturally propagated for providing a slightly heterozygous seed for planting purposes. Such a procedure would be expected to bring in plasticity in

respect of adaptive genes in such synthetics which may lead to their wider adaptability.

SELECTION

Selection is by far the most important breeding method which has been applied with very considerable success, from time immemorial, for the amelioration of crop plants. The object of all selection work, whether it is done in naturally varying populations or in variations created through artificial hybridisation or induced mutations, is to pick out from the myriad just those individuals which will be forerunners of future lines or strains showing a marked improvement over the pre-existing populations. It is to this indefinable judgment of unmeasured characters which springs from what may be described as plant breeding sense, or in other words ability to unmistakably 'spot the winner', that the great breeders of the past have owed their success. In this context, plant breeding has often been considered to be more of an art. However, recent developments in genetics and in the application of more discriminatory statistical methods for the tackling of genetical and plant breeding problems have resulted in the refinement of selection techniques which have enabled the plant breeder to handle his material with confidence and in a thoroughly scientific manner (Panse, 1942). The various selection techniques, ranging from the earlier, empirical mass selection method to the more recent ones, which have made possible the distinction between the phenotype and the genotype, are outlined below.

Mass Selection. This is the simplest type of selection and is often practised in indigenous or introduced material during the initial stages of crop improvement for obtaining useful results quickly. In this method, selection consists in marking out, in a field, a large number of what the breeder may consider to be good looking plants in respect of yield and, in the case of cotton, maturity, boll size, staple length and other fibre properties and freedom from pests and diseases. At harvest, the seed of all these plants is bulked together for the next year's sowing and the same process of selection is repeated year after year, the plant breeder holding the same ideal, with regard to the type of plant he wants for making progress. The principal disadvantages of this method lie in the facts that: (*i*) selection is on the basis of the appearance of the individual plants (phenotype) alone, and not on their breeding behaviour (genotype); some good looking plants may fail to transmit their good characters to the progeny; (*ii*) good looking plants may represent natural hybrid which will not breed true in the next generation; and (*iii*) in this process, seed of genetically good and bad plants becomes mixed. However, a good measure of success was achieved by the use of this method in the earlier years of cotton breeding in India, for instance, in *G. arboreum* in Madras (Anon.,1954). The first commercial types of *hirsutum* cotton in India, such as Dharwar-Ameri-

can, Dodahatti Local, Cambodias, etc., were the products of unconscious mass selection in introduced material.

Progeny Selection Methods. The selection of individual plants from cultivators' fields (also termed 'Primary Selection'; Mason, 1938) and evaluating the performance of such selections by plant-to-row testing, is the plan usually followed by the plant breeders. This method, stemming from the classical work of Johanssen on pure lines, has been widely practised in India as well as in other cotton growing countries, for cotton breeding. The selection is mostly based on the appearance of the plant in relation to the ideal plant envisaged by the breeder. From each selected plant, selfed seed is obtained for growing the progeny and in desirable progenies the cycle of selection, selfing and progeny testing is repeated for several years until a number of homogeneous lines, pure lines, or in Brown's (1953) words 'pedigree lines' become available for testing against the local bulk populations. The best among such lines are released for distribution as improved varieties.

The success of such selection work depends upon the amount of genetic variability existing in the populations handled, the intimate familiarity, on the breeder's part, with his crop, the scale on which selection work is undertaken (the larger the number of initial selections handled, the greater are the chances of getting a useful type) and the thoroughness with which the selected progenies are studied for the rejection of unsuitable plants or lines. The importance of such extensive and intensive selection is all the greater in cotton breeding. For, in selection work, valuable combinations of genes may be permanently lost unless full attention is given throughout the period of selection to all the morphological and physiological factors bearing on yield and quality (Harland, 1919).

As early as in 1919, Harland stated that the characters of single plants afford only a slight guide to the kind of progeny they will produce and that, therefore, selection should be shifted away from the single plant to the mean of the strain. Techniques have, therefore, been developed not only for assessing the breeding behaviour of individual plants in respect of quantitative characters but also for determining the amount of genetic variability in plant populations which would serve as a guide in selection programme. For, selection would obviously be fruitless in populations not possessing genetic variability at the requisite level. Again, in selection work in cotton, two methods have most commonly been used; mass selection, in early years, and individual selection leading to the evolution of pure lines, later on. The disadvantages of the former have already been pointed out. Regarding the pure line method, Harland (1949) has expressed the opinion, after surveying the history of cotton breeding, that pure line selection should not be practised in cottons other than the finest; instead a mixture of strains should be multiplied, each strain having to conform to a series of specified genotypic standards

before acceptance as a component of the mixture. On the basis of all available evidence, he estimated that a loss of the order of 10 per cent. or more in yield would result by the use of the pure line method, the loss being attributed to the homozygousising of about 30 per cent. of the loci concerning vigour which are expected to remain heterozygous under conditions permitting natural cross pollination. Besides, such massing of genotypes is conducive to wide adaptability. The work of Richmond (1951), Simpson and Duncan (1953), and Knight and Rose (1954) supports the view that, for retaining genetic plasticity in improved varieties, a certain amount of genotypic mixture should be practised.

A number of techniques of selection and testing have been evolved to meet above mentioned objectives. These are outlined below.

(*i*) *Type Selection:* Cook (1932) emphasised that adaptability was as important as uniformity and advocated the need for maintenance of desirable varieties of uniform type, especially from the viewpoint of the processor. He suggested that this could be attained by a combination of progeny and type selection rather than selection for a specific set of variety characteristics as from a single homozygous plant. The practice of type selection then would serve to provide practical uniformity in such important characters as fibre length and quality, at the same time allowing genotypic diversity sufficient to increase adaptability. He also suggested that groups of progenies should be maintained in various regions to cover the environmental range required.

(*ii*) *Purity Chequer:* The use of a 'target diagram', plotting the measurements of single plants for any two pairs of characters as a test for purity of a cotton variety was first described by Balls in his book: 'The Cotton Plant in Egypt (1912).' The plotting of any hundred plants for, say halo length and ginning outturn allows obvious off-types to be eliminated. However, this method cannot give any measure of the purity of the variety, as there is no means of knowing how much spread to allow for the environmental range. Brown (1932, 1953) introduced some refinements in this technique for comparing different strains of the same variety. Comparisons are made, for each variety, between the bulk stock as propagated and one or more single plant lines which are destined to be used as replacement stocks. The layout of the Chequer consists of 10 plants of each strain which are space-planted in a row and the series is repeated 10 times, making a 100 plants of each strain. On each of these plants, measurements are recorded in respect of halo length, ginning outturn, 100-seed weight, weight of seed cotton per boll, etc. For each character pair, a target diagram is made by plotting a correlation diagram of the two characters, recorded on all the 100 plants, on a paper ruled logarithmically. The circular nature and close grouping of the target diagram indicates the purity of the strain. Brown has used this technique successfully in Egypt, not only for the purification of the type, but also for

making new selections which may ultimately replace the original type. For maintenance of varietal purity, types within the general mean of the bulk but with greater purity are selected. New selection is done by choosing the stocks in which means for any character significantly deviate, from the general mean of the type, in a desirable direction, and making them the basis of fresh selections which are targetted again and compared with the mother strain for all possible characters. If the difference is distinct and desirable, the new selection may be propagated separately as a new variety. In this way a number of improved stocks were isolated from several of the Egyptian varieties.

(*iii*) *Line Test:* Trought and King (1934) described a method of testing small family bulks. The method involves sowing a 100 metre family row with a 100 metre control row on either side of it and guard rows outside these. Comparisons are made in sets of three plants; one family plant against the mean of two control plants which correspond exactly to it in position and spacing.

(*iv*) *Replicated Progeny Row Technique:* Hutchinson and Panse (1937) developed this technique at the Institute of Plant Industry, Indore, and it is now being extensively used in cotton breeding projects all over the country (Kalyanaraman and Santhanam, 1955). The principle underlying this technique has since been adopted in several other countries also in formulating selection techniques. As mentioned earlier the importance of basing selections, in cotton breeding work, on family means was brought out by Harland (1919). The techniques of Brown and Trought involved observations on replicated rows. However, the essential difference between the replicated progeny row technique and the 'Purity Chequer' of Brown or the 'Line Test' of Trought lies in the crucial fact that the replicated progeny row technique uses besides replication, randomisation, which is so essential for obtaining unbiassed mean values.

To make a progressive sifting of the material possible, controlled testing from the stage of single plant progenies to the final variety trials is necessary. While selection in respect of gross morphological characters can be carried out on eye judgment, for polygenically inherited variable characters such as yield and quality, comparisons in unreplicated progeny rows are of little value and replication should be resorted to from the earliest stages.

For replicated progeny tests, experimental designs in randomised blocks are the simplest and most flexible (Panse, 1941b). The amount of good seed produced by a single plant is usually the limiting factor, and with small plots that are inevitable in such cases, the available seed can be more efficiently utilised by increasing the number of replications rather than increasing the size of the plot; the usual practice is to have 10 replications of single row plots consisting of five plants each. The plots may be arranged in one or more rows so as to make the blocks as compact as possible. Randomised block trials with 60 to 80 progeneis have been found to be manageable without difficulty.

When plants are selected from each of a number of progenies or from the F_2s of different crosses, the resulting sister progenies can be grouped together into families. In all such cases two types of comparisons can be properly made; one for selecting the most promising families, and the other for selecting the most promising progenies in the selected families. For testing such material, Hutchinson and Panse (1937) have advocated the compact family block design as being the most suitable. In this design, the progenies making up a group, or family, are first randomly arranged in a compact plot and then the plots corresponding to different groups are randomised in the main block. The statistical analysis is carried out in two stages, as in split plot experiments. The comparison between groups (families) is based on the error variance of the large plots, and of progenies within groups on the variance of the single row progeny plots. Two other advantages of the compact family block design are, the possibility of providing non-experimental margins for family plots where necessary, and the ease of discarding undesirable families on the basis of field observations. Selection of single plants in selected progenies, as parents of the next generation progenies, is the weakest point in breeding techniques, as it is entirely dependent on phenotypic values. The commonsense consideration of distributing this selection over the whole experiment, instead of restricting it to a group of outstanding values in one part, is supported by statistical reasons, which show the advantage of basing single plant selection on the deviation of plant values from the mean of the plot to which they belong (Panse, 1940).

For testing a very large number of progenies or in cases where very limited seed is available for certain progenies, the use of 'missing plot technique' and incomplete blocks design developed by Yates, has been advocated.

By the use of replications and randomisation in this technique, not only can quantitative measurements, such as yield or plant number, be statistically analysed by the analysis of variance method, but it is also possible to carry out an analysis of co-variance between two or more characters. Such a co-variance analysis between yield and plant number in the progeny row trials appears to be particularly necessary in order to reduce that part of the error in yield comparisons which is associated with stand, and further to separate the progenies whose better yield is due to the higher yielding capacity of the plants from those which give a better yield on account of a superior stand. The application of this technique no doubt involves considerable labour and detailed statistical computations, but these are amply repaid by the fact that the technique provides an objective procedure for selection, thereby increasing its effectiveness.

The replicated progeny row technique not only helps in reducing the environmental contribution to the variance but it makes possible the partitioning of the total variance into its genetic and environmental components, thus minimising "environmental fluctuations while maintaining genetic contrasts."

It also enables comparison of genetic variances within and between families, and it is an efficient technique for detection of genetic variability in families in which it is desired to know whether they possess genetic variability at an exploitable level.

(*v*) *Mass Pedigree Selection:* One of the major drawbacks of the progeny selection method employing the pure line principle is that it results in too much homozygosity of strains which, in the case of cotton, has often been found to affect their vigour, productivity and adaptability to varied environmental conditions. Harland (1949) critically surveyed the history of cotton breeding and came to the conclusion that, from the industrial standpoints, the pure line concept has been of the greatest possible importance to the fine cotton trade and that, therefore, the policy of pure line breeding in them should be maintained. To this end he cites the experience of Balls, in Egypt, who advocated pure line selection as an ideal method for cotton improvement. With regard to coarse cottons of medium to short staple, however, it has according to Harland (1949) never been demonstrated that pure lines spin better than mass selected populations; it is, therefore, possible to grow mass selected populations in them without detriment to the industry, provided that standard values for length and hair weight are maintained in the selected material and provided that precautions are taken to reduce to a minimum genotypes not conforming to the standards laid down. He (1944, 1949), therefore, suggested that the march of selection should be along the following lines: (*i*) pure line selection should not be practised, but a mixture of strains should be multiplied, each strain having to conform to a series of specified genotypic standards before acceptance as a component of the mixture; (*ii*) a series of norms should be established which should cut off the frequency curve of *means of strains* for the character at a varying position dictated by the importance of the character in question and by the urgency with which progress is deemed necessary. In some cases, as in yield, all lines would be discarded which fell below the mean of the general population of lines. In others, the lower quartile could be discarded; in still others, only the upper quartile would be retained.

Accordingly, Harland (1949) inaugurated a system of breeding, termed 'mass pedigree selection', which he successfully employed in the improvement of Tanguis cotton (*barbadense*) in Peru. The main features of the system and the essential steps involved are outlined below.

First Season:

1. A large number of single plant samples from the heterogeneous commercial crop are examined in order to obtain quantitative estimates of the main characters which are to be worked on, to establish specifications or norms of the characters required, and to select such plants as satisfy the norm test.

SECOND SEASON:

2. A number of single plant samples which have passed the above preliminary test are grown in progeny rows (one replication).

3. The mean of each progeny is determined for the character under consideration.

4. The progeny means for each character are arranged. At first, bulk samples from these progenies are examined. Progenies, whose means fall on a certain segment of the distribution curve are selected; the segments have to be chosen by the breeder on the basis of the relative importance of one character as compared to the others, and to the original variability of the material (bulk norm test). Then, all single plants of the lines, passing the bulk norm test are examined and plants failing to conform to the norms are eliminated (single plant norm test). From this material, an elite of, say, 200 plants is selected.

THIRD SEASON:

5. The elite selections are grown in progeny rows with an adequate number of replications (usually 10). Bulk norm test is applied for eliminating undesirable lines, and also for eliminating lines which in yield of seed cotton per plant are below the mean of the whole population of lines.

FOURTH SEASON:

6. The seed of lines which pass the above norm test are massed together. This seed may either be increased for distribution, or it may constitute a bulk planting in which another selection cycle may be started.

According to Harland (1949), continuous selection by this method for any measureable character tends to produce a system of gene frequencies resulting in the manifestation of the character at a higher level through the elimination of alleles, the combinatory effects of which are ordinarily antagonistic to the standards laid down for the character. The mass pedigree selection system makes full use of the principle of progeny testing and at the same time is designed to preserve genetic variability through the use of a large number of lines and a broad adaptation base by propagating massed lines under varying seasonal and other environmental conditions. Furthermore, the method would preserve certain genes for vigour as heterozygous loci, a condition which, in Harland's view, would give the stock an advantage over strains in which the same genes were homozygous. The system is similar in principle to the old type selection methods, but recognises, defines and measures the component characters of the type and provides a much more critical progeny test.

(*vi*) *Bulked Progeny Test System* (*Texas Method*): Discussing the pure line concept and the necessity to select for yield on a broad genetic base in relation to cotton breeding, Richmond (1950) states: "On theoretical grounds there is no reason to suspect that pure lines of cotton are different in behaviour from

pure lines of any other crop. The practical consideration of a pure line involves both uniformity and superior performance. Both cannot be sought rapidly and at the same time. Selection for high yield 'on a broad genetic base', which is necessary if decreases in production are to be avoided, involves the simultaneous handling of a number of characters over a relatively long period; such a procedure does not lead rapidly to homogeneity. Failure to observe the 'broad base' concept and the desire for rapid development of uniformity in one character at the expense of all others has taught many cotton breeders the severe lesson that the probability of obtaining a 'uniformly bad' strain is much higher than that of obtaining a 'uniformly good' one." Because of the wide range of soil and climatic conditions in Texas (U.S.A.), the American Upland cotton breeding programme of the Texas Agriculture Experiment Station emphasises particularly the conservation and maintenance of genetic variability in progeny tests extending over a number of years. This station largely employs varietal hybrids, in handling which the bulked progeny test system (Richmond, 1951) is followed. The steps involved in this system are given below.

1. Single plants are selected in F_2 and selfed and open pollinated seeds are harvested separately. The selfed seeds are stored in such a manner as to preserve the germinating qualities over a period of several years.

2. Duplicate progeny rows are grown from open pollinated seeds in randomised blocks in F_3; 'check' rows of the best commercial variety for the area are grown at 8 to 10 row intervals throughout the plots as a standard of comparison for productivity, maturity, etc. Progenies are grown in large numbers and selection is first made on the basis of comparison with the 'check'. Only those progenies with good 'scores' in both replicates are marked for further attention. After the scoring, a random sample of bolls is harvested from one of the 'duplicate rows' of each progeny selected to supply material for other agronomic, and fibre and seed determinations; the random boll sample also supplied seed for testing in F_4.

3. In F_4 generation the bulked seeds from F_3 are planted in a randomized block design of four to eight replications; two or more 'check' varieties are entered in the design on the same basis as the new strains to be tested. The plots are harvested for yield as in an ordinary strain or variety test, and the yield of the 'check' (or checks) is used as a standard of comparison. Agronomic and fibre data are obtained from random boll samples as in 2 above, and the seeds of the strains that are selected are used in another testing and selection cycle.

4. When the testing of random boll bulks has reached F_6 to F_8 a sufficient amount of data will have accumulated on the strains that have not been discarded earlier to furnish a basis for decision on subsequent disposition. Presumably all the remaining strains will then have acceptable means for yield

and other characters under study. Depending on how well the random boll samples actually represented each family and also assuming less than 10 per cent. cross pollination, maximum heterogeneity of superior biotypes will be preserved in F_6 to F_8 but the majority of individual plants will have approached practically homozygosity. The variability exhibited within each of the strains that reach F_6 to F_8 stage also will depend on the extent to which mean yield rather than uniformity is taken into account in retaining or discarding whole families from F_3 onward. This poses a critical decision, for the breeder may make a mistake by either selecting for uniformity too soon or maintaining variability in the breeding material too long.

5. Usually it will be desirable to reselect on an individual plant basis in the bulked material of families at the end of the first testing cycle (F_6 to F_8), and through such selection it should be possible to raise the mean performance of some of the reselected progeny over the mean of the parent family. The second cycle of testing should seldom proceed past the second or third generation before the selected second cycle family bulks are ready for multiplication as new agricultural strains or varieties.

6. Whenever possible, strains with similar characteristics are massed and carried in subsequent strain and variety tests as massed-line varieties.

7. In areas where cross pollination is extremely high it may become necessary to resort to the stored selfed seeds of the F_2 plant corresponding to each family that persists at the end of the first testing cycle. Increases from selfed seed, in such cases, should be made before the first test cycle is concluded, in order to save time.

(*vii*) *Sudan Technique :* For meeting the special requirements of the very vast and highly variable cotton tracts in the Sudan, Knight and Rose (1954) have recently evolved the 'Sudan Technique' of cotton breeding. The technique has been devised so as to incorporate in it the advantages of selfing, without reducing the plasticity, as well as to retain the potentiality for making further advances. The essential features of the technique are:

1. Starting with a large number (not less than 1,000) of individual plant selections.

2. Growing them in the next season as progeny rows with numerous controls and selfing them, both for preventing contamination and for 'locking up' of a portion of gene complexes by rendering them homozygous. The selfed seed is stored for future use.

3. Statistical comparison of selected progenies against the parent variety, mainly for yield, for further selection of those which are distinctly superior.

4. Bulking the selfed, stored seed, of stage 2 above, of the progenies which have passed the statistical test and growing it in an isolated 'panmixis' plot located at a place where natural cross pollination is high (the authors mention Shambut where out crossing is about 25 per cent.). Random mating in the 'panmixis' plot allows subsequent segregation

which 'unlocks' the gene complexes to build up higher (and lower) levels of minor genes.

5. Growing the bulked seed of the 'panmixis' plot at least for one more generation in order to release variability and then making again about 1,000 plant selections with which the cycle is to be repeated from stage 2 onwards.

About three cycles of the above sort are expected to be sufficient for breeding an improved variety.

(*viii*) *Cumulative Selection:* With reference to the 'panmixis' mentioned in the Sudan technique, as also to those mass selection techniques where natural out crossing on a considerable scale is implicit for the success of the particular technique, it may be pointed out that in areas where the extent of natural crossing does not exceed two or at the most five per cent. (e.g., India as it appears from relevant literature), the fullest benefit may not accrue from the application of these techniques (Bhat, 1955). In such areas, it may perhaps be worthwhile studying insect behaviour with a view to locating such cotton growing regions where the maximum amount of natural out crossing can be obtained. Alternatively, a system of extensive hand pollination, in all possible combinations, may have to be advocated. Such a procedure is adopted in the 'Cumulative Selection' technique recommended by Richmond (1950). In this method, lines bearing the character under study, from as many diverse sources as possible or practical, are selected in F_2. After isolating relatively good complexes, but without carrying on selection in each line to its ultimate conclusion (complete uniformity), the selected lines are immediately crossed in all possible combinations and carried to a new F_2 in bulk. Selection for the character is then practised again, and the cycle repeated until the level of acceptability is reached.

SECONDARY SELECTION

The most important selection which a plant breeder makes is primary selection. The primarily selected individual plants, after undergoing progeny selection, constitute the source of improved varieties. In this process the selection techniques used may be pure line breeding or one of the methods involving the massing of selected lines, outlined above.

The question asked is whether once the improved varieties have been evolved and released, there is scope for secondary selection or reselection. Obviously, the scope for such reselection will depend upon the extent of residual genetic variability contained in these populations. Such variability may creep into them as a result of mechanical mixture, natural out crossing or progressive accumulation of favourable or unfavourable mutations.

In the case of 'massed' strains, there is obvious need for starting fresh cycles of reselection from time to time, as has already been indicated earlier while discussing the relevant selection techniques, such as the mass pedigree system, the Sudan technique and others, for further amelioration of the selected

populations. Kohli (1952) applied the mass selection technique, as a quick and less expensive measure, to elevate a degenerating improved variety, 289F/K.25 by secondary selection.

Regarding the need for or advisability of, exercising secondary selection in superior varieties established through pure line breeding, Mason (1938) expressed the opinion that in most cases it is the primary selections that have given spectacular results, secondary selections having been of only small benefit. He considered that in the process of making secondary selections, valuable attributes might be lost, and, therefore, recommended concentration of efforts on increasing variability of the initial stock for carrying out primary selection. Ramiah (1941), however, pointed out that the ordinary breeding methods are not sensitive enough to separate genetic variance from environmental variance and recommended the use of the improved technique of replicated progeny row for detecting residual genetic variability. Hutchinson and Kuber Singh (1936), using this technique, demonstrated the possibility of further improving Malvi cottons (*arboreum*) in India. Manning (1956) also remarks that one of the possible explanations for the persistence of variability which was observed in inbred cottons is undoubtedly that with the statistical techniques that were used, it was possible to detect those strains in which there was sufficient genetic variation to provide scope for further improvement. Referring to Mason's (1938) opinion, that many of the largest and best established improvements in varietal behaviour in cotton were the result of 'primary selections', Manning (*loc. cit.*) states: 'It is in the nature of variability that it should be possible to pick out from an unselected, highly variable crop, components differing widely from the mean. Often, and especially when a crop is comparatively new in an area, or is exposed to such new circumstances as attacks from pests and diseases not previously encountered, selections may be made that will be vastly superior to the unselected material. What is not so generally realised' is that the slow, patient, progressive improvement of an already well adapted stock may over the years yield a greater return than a single spectacular stride, and moreover, that what is known of evolutionary change suggests that this kind of improvement is more comparable with natural evolutionary progress than is the quick response of a successful primary selection." Working in Uganda within the *hirsutum* variety, B.P.52, and applying a selection index, involving bolls per plant, seeds per boll and lint per seed, he obtained a total measured improvement, in yield, of some 30 per cent. after six generations of selection. He, therefore, emphasised the significant point that genetic variation of a magnitude sufficient enough to lead to practical yield improvement has been demonstrated to exist after seven generations of inbreeding. The findings of Manning are in agreement with the earlier experience of Hutchinson (1940) who commented on the failure to achieve 'pure lines' in Sea Island cotton, of Harland (1934) who found that selection for lint index in the Montserrat Sea Island variety of cotton led to yield improvement despite 17 genera-

tions of self-fertilisation, and of several other workers (see also the section on effects of inbreeding).

Panse (1941), while discussing the inheritance of quantitative characters with special reference to cotton breeding, stated that the same amount of genetic variability may result from a few genes with large effects or from a number of factors producing effects of varying magnitudes ; while there will be an immediate response to selection in both cases, progress by further selection will soon be slowed down if only a few factors are operating, whereas selection can be profitably continued for a longer period in the other case. A majority of the economic characters in cotton such as the important ones relating to yeild and quality, are polygenically inherited and considering the degree to which environment can modify the expression of these characters it is difficult to imagine single lines homozygous or nearly so for all, or even a majority of such genes. It is perhaps due to this that Harland (1934) found selection in Sea Island to be effective even in material selfed for 17 generations and that the Egyptian cotton breeders obtained continued responses from close selection (see also Christidis and Harrison, 1955). Fikry (1937), working with Egyptian cottons, has stated that through reselection, the general average staple length could be increased from 31·5 mm. to 35·5 mm. Boza Barducci (1949), working in Peru, could increase the staple length to 1-1/2″ or 1-17/32″ through reselection in the established type, Tanguis. In Morocco, Dufresse (1951) obtained high yielding, high quality and long staple (48 mm.) cotton, e.g., Pima 67, through judicious reselection. With regard to *G. hirsutum* Peat and Prentice (1938) questioned Mason's (1938) emphasis on primary selection and cited as evidence his successful work in southern Rhodesia on reselection in the variety U.4 (*G. hirsutum*). Garrido (1947), discussing the importance of reselection in *hirsutums* in America, has stated that in the pedigreed lines of some of the commercial varieties, viz., Batangas White, Kapas Purao and Ferguson, the increase in length of fibre was 1/16″, 1/4″ and 3/16″, respectively, over their old parent stocks. Simpson and Duncan (1953) have stated that major improvement was obtained in lint length through reselection in progenies grown from reserve seed stocks ; in Stoneville 5, a total gain of 0·169 inches in lint length was obtained. Panse (1941), estimated heritable variability, in respect of halo length and ginning percentage, in three *arboreum* crosses and discovered that in the parental strain, inbred for over 10 generations, complete homozygosity had not been attained and certain amount of genotypic variability persisted.

Viewing this problem from the standpoint of American Upland cotton breeding, Richmond (1950) states: "It has been shown that the germ-plasm, which constitutes the genetic reservoir, from which present agricultural varieties have arisen, has yielded a number of productive types which are well adapted to their respective geographic areas of growth. Reselection

within varieties, and even within the progeny of varietal hybrids, over a period of many years, inevitably has resulted in severe inbreeding and the elimination of many beneficial as well as deleterious genes which are present in the native stocks. Since American Upland varieties in the United States are all inter-related and probably descended from not more than a dozen original introductions, it is doubtful that future requirements of special fibre properties, disease, insect and drought resistance, mechanical harvesting, and other specialised uses and properties can be met by the usual selection methods within present cultivated varieties." These remarks of Richmond may well apply to cotton breeding in India, especially with reference to *herbaceum* and *hirsutum* cottons.

Richmond (1950) has, therefore, suggested two approaches, or a combination of two approaches, to further progress and improvement : (*i*) development of more precision in the breeding programme through refinements in method and design to provide for more discriminatory statistical tests, and the establishment of indices which will measure the genetically potential performance rather than the actual end result behaviour; and (*ii*) introduction of new germ-plasm into the breeding material, from outside the range of that now present in current agricultural varieties.

HYBRIDISATION

According to Christidis and Harrison (1955), perhaps the first attempt to obtain new cotton types by hybridisation was made between 1786-90 by the Danish colonist, Rohr, on the Island of Saint Croix when he suggested the cross between his 'Curacao' and 'Carthagena' cottons for combining quantity with a fine silky fibre. He actually crossed his Indian and Brazilian cottons and obtained a cross of great value, also maturing earlier than either parent. In India, Burns is reported to have crossed what he called *G. herbaceum* and *G. arboreum* (Watt, 1907) and obtained an F_1 showing a higher ginning percentage and fibres of better quality. In the U.S.A., John Griffin in 1867, produced by hybridisation the variety 'Griffin', in which work he used what is essentially the backcross method.

Hybridisation may be made between plants within a variety, between different varieties belonging to the same or different regions or between species possessing the same or different chromosome numbers. Usually, selection is exercised in straight progenies of crosses made between two parental strains, although breeders may think it necessary to cross together three or more varieties for meeting specific objectives. In the F_2 generation, a great variety of plant forms results, which represents all possible combinations of genes from the parental strains entering the cross. The larger the F_2 population grown the greater are the chances of obtaining desirable gene combina-

tion. A large number of selections are made in the F_2 generation and their selfed progenies are tested in further selfed generations until homogeneous lines combining desirable traits are obtained for, first, small scale and later large scale trials. The larger the number of genes governing a desirable trait, the longer it takes to obtain true breeding lines exhibiting the maximum expression of the useful combinations of characters. When it is desired to transfer, to an otherwise desirable, adapted strain or variety, one or a few characters (each governed by one or a few genes only) contained in another strain which is economically inferior, the two strains are crossed together and a backcross programme, using the desirable adapted strain as a 'recurrent' parent (possessing the greater number of desirable characters), is usually practised. The application of the backcross method to cotton breeding will be discussed later.

Choice of Parents. This is one of the most crucial points on which the plant breeder has to decide while initiating a hybridisation programme. In choosing varieties or strains for crossing, it is obvious that they should possess the properties to be combined and show as few undesirable characteristics as possible. It has, however, been often observed that, by hybridisation, new genetic complexes can be obtained with little or no apparent relation to the characters of the two parents. Ramiah (1941) considered this question in relation to ginning percentage and halo length in *G. arboreum* and suggested that it is not always the type with a high mean value for either of these atributes that is able to transmit the character to the progenies ; for example, *cernuum* a high ginning but poor quality cotton is just as good as V.434 and K.1 in its contribution to fibre qualities in the progenies. From his experience in Egypt, Brown (1939) made a significant statement: "The most general conclusion is that from hybridization new gene complexes can be selected with little or no apparent relation to the characters of the two parents."

It is a common place of plant breeding work, that provided the parents for hybridisation have been properly chosen, the chances of selecting desirable genotypes are the greater, the larger the size of populations grown in the F_2 and the subsequent segregating generations. Land and personnel usually being the limiting factors it is difficult properly to handle sufficiently large populations of a large number of crosses; the breeder would, therefore, wish to grow extensive populations of a smaller number of crosses. Under such circumstances, it becomes highly desirable to be able to choose with certainty only such parents for crossing as would give forth a larger percentage of useful combinations.

Combining Ability. The plant breeders observe very frequently that more desirable segregates are obtained from some crosses than from others. That is, some varieties are good parents, as judged by their ability to transmit high yield and quality to their progeny in crosses; others are less desirable.

Harrington (1932) suggested that an analysis of the characters that could be studied in an F_2 population would provide a means of predicting the value of a given cross. Very interesting results were obtained, through the use of this technique in wheat and barley (Hayes, Immer and Smith, 1955). Ramanatha Ayyar (1941), stressing the need for a more intensive programme of hybridisation of cotton in India, focussed attention on the following points: (*i*) crosses between varieties of the same species do not produce the same proportion of desired genotypes; even unpromising strains may yield valuable genotypes when used as parents in crossing; (*ii*) crosses involving the same parents may behave differently in different localities with regard to the useful genotypes they yield; (*iii*) direct hybridisation between species is often not fruitful; (*iv*) crosses between biotypes differing widely in the phenotypic value of a single character (such as shortest lint x longest lint) would not give stable segregants exhibiting the maximum expression of the character together with other desirable plant and fibre characters because of the fact that such characters are often determined by the additive action of numerous genes; (*v*) parents for hybridisation should be chosen from varieties grown in tracts with similar climate or from varieties cultivated in the neighbouring tracts; (*vi*) parents should differ only in a few characters; crossing between plants that are morphologically similar would offer great possibilities for selection as most of the genes would be of dominant type; (*vii*) all the different ecotypes belonging to the same species should be crossed with the local ecotype; and (*viii*) genotypes can be built up by complex hybridisation, although there is a likelihood of greater hybridity leading to variability stemming from heterosis due to which it may be difficult to obtain stable, superior segregates. Ramanatha Ayyar (*loc. cit.*), therefore, suggested that small populations in each type of cross may be grown to determine the parent that would give a large proportion of combinations of economic value.

Heritable variability can be conceived of as consisting of two components: one resulting from a purely additive action of genes, and the second from the presence of dominance and other non-additive gene interactions. The first component, termed 'genetic' by Fisher (1930) is really more relevant than the gross heritable variability in determining the response to selection. The genetic portion of the variance in a population can be estimated by growing progenies from random individuals belonging to the population and taking the regression of the progeny means on the parental values (Panse, 1940). The regression coefficient then represents the genetic fraction of the observed variability in the population. Panse (1941) stressed the importance of obtaining knowledge regarding genetic variability in progenies of crosses, as it would determine the order of their suitability for selection and applied this method in three crosses of *G. arboreum*. Panse (1941) also suggested that it would be advantageous to be able to estimate genetic variability, even though approximately, at as early a stage as possible. According to him, parental differen-

ces are probably not very useful for this purpose, as the same amount of genetic variance can be produced in crosses between parents showing varying magnitudes of differences. He, therefore, recommended the study of the F_1 behaviour as being more promising; the F_1 values could be compared with the genetic variability in the F_2 in a series of crosses. Kelkar, Chowdhary and Hiremath (1947a) undertook such a study in relation to choice of parents for hybridisation in *G. herbaceum*, and Kelkar and Kaiwar (1947) in *G. hirsutum*. They confirmed the statement of Panse (1947) that there is correlation between the F_1 and F_2 means of crosses involving even geographically separated types. As regards interspecific crosses they observed that both F_1 and parental means are useless for predicting their value; it is better to base such prediction on F_2 means. In the case of intraspecific crosses, if the F_1 does not show a marked enhancement over the parental means, its F_2 mean can be reasonably predicted; the value of the cross would then depend on the extent of genetic variability in F_2. In general, however, they observed that it is not possible always to predict the F_2 mean on the basis of the F_1 mean, because dominance, heterosis and maternal effects "complicate the F_1 values to a larger extent." On the basis of their study, these authors made the following recommendations: (*i*) for the betterment of local varieties through hybridisation, it is better to choose the parents from the same species; (*ii*) geographically separated types, but belonging to the same species, prove better parents because F_2s of such crosses show higher co-efficients of variability; (*iii*) crosses showing magnified hybrid vigour do not seem to be desirable; (*iv*) crosses, the F_2s of which give means equivalent to the mean values of the parents involved, can be chosen with better confidence. They are, on the average, productive of balanced and desirable genotypes in greater numbers. The F_2 mean of such crosses can be predicted from the F_1 or parental mean; and (*v*) enhancement of the F_1 means is possible, even in the absence of hybrid vigour, due to accumulation of genes, dominance, epistacy, physiological associations, etc. In the case of heterosis, a sudden drop in the F_2 mean would be noticed. Dominance would prove to be an impediment in further selection. Accumulation of genes and physiological associations would prove to be beneficent. In such crosses, the value of the variety as a parent can only be assessed on its F_2 mean and extent of variability. Avtar Singh (1950—Unpubl.), working in the Punjab with intraspecific crosses in *G. hirsutum* obtained results substantially in agreement with those mentioned above. Bolsunov (1937), however, recommends quite differently, namely, that breeders desirous of obtaining high yielding hybrids with longer lint, superior to its parents, should select from combinations which show maximum heterosis in the F_1.

Transgressive Segregation. It is not infrequently noticed in the course of plant breeding work that certain segregates are obtained in the F_2 or sub-

sequent generations of a cross, in which the magnitude of expression of certain characters transgresses the limits covered by the parental strains. The transgressive segregates represent individuals in which several additive genes have accumulated in the homozygous condition. A case in point is the very variable material obtained from an intervarietal cross of two medium stapled types of *G. hirsutum*, viz., 45F and L.S.S., from which the Lasani strains of Pakistan and the L.L. (Long Lint) series of the Punjab (India), possessing staple between 1-1/16" to 1-1/8", have been developed (Sikka, 1957). Ramiah (1941) stated that *G. arboreum* race *cernuum*, despite its very short staple, possesses some genes for long staple. Fikry (1953) working with Egyptian cotton (*G. barbadense*), recorded the maximum staple length in Giza 49 (45 mm.), which was an outcome of a cross between Giza 26 (40 mm.) and Giza 29 (38 mm.).

Character Inheritance and Selection in Hybrid Progenies. In making a progressive selection in hybrid progenies, a breeder has to reckon with the genetic structure of the characters concerned, i.e., the number and nature of genes governing them, and in cases like cotton where selection has to be exercised simultaneously in respect of yield and fibre qualities, attention has to be given to the nature of their mutual relationship (correlation). Thus, when the aim is to combine desirable values for two or more characters, the cross combination that contains the highest amount of genetic variability in each of the characters concerned is naturally the most suitable (Panse, 1941). If the characters are inherited independently, there is no real difficulty in securing combinations containing the maximum possible improvement in each character. Even then, combinations of extreme values cannot be hoped for, because, with any appreciable number of factors segregating, such combinations form a very small fraction of the population and are, therefore, rare in the amount of material which is usually possible for the plant breeder to grow. The need for growing hybrid progenies on an extensive scale is thus clear. It is all the more important when characters are genetically correlated due to linkage or other causes; the scope for simultaneous improvement is restricted, depending on the strength of the association. If two characters, A and B, are independent, selection for any value of A will not affect the mean value, or the genetic variability, in respect of B. But, if A and B are genetically associated with 'r' as the correlation co-efficient and σ_A^2 and σ_B^2 the genetic variance in respect of A and B, selection for A will also change the mean value of B by a quantity equal to r $\frac{\sigma_B^2}{\sigma_A^2}$ times the change in A, and reduce the genetic variance about this mean by a quantity, $r^2\ \sigma_B^2$ (Panse, 1941). Genetic correlations can be estimated from progeny means which are practically free from environmental influence to which individual plants are subject. According to Anderson's (1939) suggestion, if a cross

is to be effected between two parents, say, one with desirable lint length and the other with high ginning percentage, desirable combinations of lint length and ginning percentage will be found in the progeny of a second cross made between a plant in F_2, having long lint and a little higher ginning, and its sib having high ginning percentage and lint length a little longer than the short linted parent (Ramanatha Ayyar, 1941). An extension of this recommendation is embodied in the 'panmixis' technique adopted in the Sudan technique of Knight and Rose (1954) and in the Cumulative Selection technique of Richmond (1950) which have already been dealt with earlier.

Wide Crosses. It has already been mentioned that for the betterment of local varieties through hybridisation, it is better to choose the parent from the same species. In intraspecific crosses, however, crossing between geographical races or between distinct ecotypes within the species is to be recommended (Kelkar *et al.*, 1947a; Hutchinson, 1938a; Vavilov, 1940). Thus Kelkar *et al.* (1947a) found a markedly higher genetic variability in the F_2 of crosses between Kumpta and Gujerat varieties of *G. herbaceum* than that observed in crosses between varieties belonging to the Kumpta region. In the improvement of *G. arboreum* in India, the race *cernuum* has often been used for the improvement of ginning percentage of the other races. Recently, in *G. hirsutum*, breeders took renewed interest in the native cottons of southern Mexico and central America as a source of new germ-plasm. Richmond, Manning, Stephens and Ware made extensive survey and collection in these areas (Richmond, 1950). Hutchinson (1951) examined this material and found that while it was useful for understanding the development of the species, it was not so in relation to breeding, as inter-racial variability is for the most part a matter of differentiation in habit characters only. As regards intra-racial variability in *G. hirsutum* race *latifolium* to which the cultivated Uplands (and Cambodias) belong, Hutchinson (*loc. cit.*) discovered that *latifolium* has rather gained in variability on spreading out into the world from its original home, which is exactly the reverse of what would be expected from Vavilov's concept of diminishing variability away from the centre of origin. Hutchinson, therefore, concludes that, so far as *hirsutum* is concerned, characters of agronomic value are not to be sought from its original home in central America, but from peripheral zones. Nevertheless, in California (U.S.A.), factors for lint strength have been transferred from Hopi (*hirsutum* race *punctatum*) to Acala (*hirsutum* race *latifolium*) and the strain Hopi-Acala has been obtained (Cuany, 1952). Thus, whatever the source of variability, the 'broad genetic base' concept of Harland (1955) is of vital importance to hybridisation programmes and recently the Indian Central Cotton Committee has taken steps to establish 'germ-plasm banks' with a view to placing cotton breeding in India on a broader and more sound footing.

Reviewing the scope of interspecific crosses, Hutchinson (1940) stated that "hybrid material that does not transgress species boundaries can be con-

fidently recommended to breeders for straight selection." However, it often becomes necessary to undertake wide crossing in order to meet specific objectives, such as special fibre properties and resistance to pests and diseases. In inter-species and other wide crosses, a very considerable portion of the heritable variability is probably 'non-genetic' (that is, not due to genes with additive effects); this would explain why straight selection does not produce the results to be anticipated from the large variation that is usually present in progenies of such crosses (Panse, 1941). Distant crossing also brings in problems of sterility, which may be genic or chromosomal, or both. Harland (1936a) suggested that stable complexes of inter-related genes are built up within each of the species ('modifier complex' of Harland) and when they are inter-crossed, the genetic balance is disrupted in the F_2 generation, giving a maze of abnormal and unbalanced types. Harland (1955) terms this as 'genetic erosion' of vitality complex. Stephens (1950) explains this as being due to cryptic structural differences between the chromosomes of these species. The backcross method of breeding is, therefore, more suited to distant crosses than selection in straight progenies. The role of interspecific hybridisation and the backcross technique in cotton improvement is dealt with in some detail here; the cytological aspects of interspecific hybrids are considered in the chapter on Cytology.

INTERSPECIFIC HYBRIDISATION

Hybridisation between species is resorted to for securing genes or gene combinations that are not normally available within the limits of a species. In addition, it may be possible to obtain increases or improvements in certain characters through what Stephens (1944) termed 'transgressive breeding' since genes favourable for intensification of a particular character may occupy independent loci in the parental species and may also act independently of one another (Richmond, 1951). In *Gossypium* there are four species comprising both cultigens and wild forms and 16 wild species (Hutchinson, Silow and Stephens, 1947; Hutchinson, 1950, 1951, 1954). There is thus a wide scope for experimental work on the possibilities of incorporating desired characteristics from cultivated or wild forms into the species of commerce. Work on these lines has been in progress in India and abroad and some useful results have been reported from time to time.

For the purpose of cotton breeding, interspecific crosses have been attempted among cultigens and between cultigens and wild types.

Crosses Between Cultivated Species. Among the cultigens, *barbadense* possesses by far the best quality of lint. This species, on the one hand, has been used in improving fibre properties of *hirsutum* and types like M.C.U. 2 in India (Jagannatha Rao, Marar and Santhanam, 1953) and Sealand and Meade abroad (Christidis and Harrison, 1955) have

been bred. On the other hand, *barbadense* itself has been improved in the Sudan with regard to disease and pest resistance by the incorporation of the necessary genes from *arboreum* and *hirsutum* (Knight, 1956). Stocks of *hirsutum* that could not be acclimatised in Gujerat tract of India have been rendered suitable for cultivation in the region by transferring into them general adaptability from *arboreum* and *herbaceum* (Pandya and Patel, 1956). Deviraj (170-Co.2), evolved from *hirsutum-arboreum* hybridisation, has shown transgressive value for fibre length as compared to the parents. Some other *hirsutum* strains resistant to blackarm and jassids and possessing fibre length ranging from 1·14″ to 1·26″ have also been isolated from similar hybrids (Jagannatha Rao, Marar and Santhanam, 1953 ; Pandya and Patel, 1958a). Pandya and Patel (1958a) have reported that a large number of inter-crosses involving the New World and the Old World cultigens are under study at Surat and that it is possible to evolve superior types for rainfed tracts that would at least spin to 50's. The ginning performance of Kumpta (*herbaceum*) cotton has been improved by hybridisation with *arboreum*.

Utilisation of Wild Species. Some of the wild species are known to possess characters that would be desirable in the cultigens. In addition some of these species have given unexpected and extremely useful character combinations in actual hybridisation experiments. These are :

1. *G. anomalum :*
   (*a*) Extreme fineness, high maturity percentage and good strength of fibre.
   (*b*) Resistance to blackarm, bollworms, jassids, leaf roller, red mites, semi-loopers, etc. (Margabandhu, 1941).
   (*c*) Narrow bracts, a feature that would ensure clean picking in cultivated cottons.

2. *G. sturtii :*
   Healthy foliage and luxuriant vegetative growth.

3. *G. stocksii :*
   Resistance to drought (Abrahman, 1940).

4. *G. somalense :*
   Resistance to bollworms.

5. *G. thurberi :*
   (*a*) Prolific boll bearing.
   (*b*) Fibre strength (latent feature).
   (*c*) Resistance to frost, wilt, gummosis and bollworms.

6. *G. armourianum :*
   (*a*) Healthy leaf growth (Pandya and Patel, 1956).
   (*b*) Fibre strength (latent feature).

(*c*) Resistance to blackarm and spotted bollworm.
(*d*) Resistance to jassids although the leaves are glabrous.
(*e*) Caducous bracteoles (desirable for obtaining clean picking).

7. *G. harknessii* :
(*a*) Waxy covering on seed hairs, which is different from that in *hirsutum*, may contribute to lustre and special spinning properties of lint (Brown and Menzel, 1950).
(*b*) Resistance to drought.
(*c*) Smooth, shallowly lobed leaves and small caducous bracteoles that will ensure clean picking in cultigens.

8. *G. aridum* :
Resistance to drought.

9. *G. raimondii* :
(*a*) Vigorous root system, luxuriant vegetative growth and drought resistance.
(*b*) Fibre strength and fineness.
(*c*) Resistance to blackarm, spotted bollworm and leaf roller. Tolerance to jassids.

10. *G. tomentosum* :
(*a*) Lint fibres fine and strong.
(*b*) Resistance to drought and jassids.

In *arboreum* and *hirsutum* cottons, strains possessing finer fibres have been isolated by hybridisation with *anomalum* (Kalyanaraman and Santhanam, 1957 ; Afzal, Sikka and Rahman, 1945 ; Pandya and Patel, 1958a). In *arboreum* (Karunganni cotton), fully fertile plants possessing long (mean fibre length 0·90") and fine (mature fibre weight *c*. $1 \cdot 50 \times 10^{-6}$ gm. per cm.) lint have been secured (Santhanam, 1958a). Co-ano-8 is one of the *hirsutum* strains evolved similarly by hybridisation with *anomalum* ; its fibre weight is $0 \cdot 102 \times 10^{-6}$ oz. per inch and fibre length is 1·17" (Pandya and Patel, 1958a). In the U.S.A., 15 years of investigations on the hybrids of *thurberi* with the cultigens has led to the recent release of breeding stocks of *hirsutum* possessing nearly 15 per cent. better spinning and 20 to 30 per cent. better fibre strength (Richmond, 1950 ; Anon., 1957b). Knight, Dark and Cuany (1953) have reported the transference of bollworm resistance from *thurberi* to *barbadense* cottons of the Sudan. *Gossypium raimondii*, itself possessing a light coat of short hairs on its seeds, has yet been useful for the improvement of halo length and ginning outturn in the *hirsutum* cottons (Santhanam, 1957—Unpubl.). The transgressive value for ginning outturn in this hybrid material was traceable to the higher density of seed hairs (*c*. 17,000 per seed) in *raimondii* as compared to that of *hirsutum* (Santhanam, 1957). Knight (1954c) introduced the gene for pilosity from *tomentosum* into *barbadense* cotton of the Sudan but the same gene produced secondary effects of poorer plant growth and shortened lint.

At Indore in India on the other hand, *hirsutum-tomentosum* hybridisation has given rise to *hirsutum* types with a pilosity index twice or thrice that recommended for conferring jassid resistance and it has been possible to break down the association of hairiness with lateness and short staple (Ganesan, 1958). Moreover at Surat, *hirsutum* types with drought resistance index value as high as 1·75 and fibre length ranging from 1·03″ to 1·13″, have been evolved from hybrid material involving the species *hirsutum*, *tomentosum* and the Old World cultigens (Pandya and Patel, 1958a). The work on utilising other wild species does not seem to have progressed very far. In several back-cross or selfed progenies of the hexaploids from hybrids of *barbadense* with *thurberi* or *armourianum*, Knight (1951) obtained no plants with deciduous or minute bracts. He, therefore, inferred that the small and/or deciduous bracts found in certain New World diploids are not likely to be transferred to the New World cultigens.

By far the most significant discoveries in these experiments have been: (*i*) transgressive inrceases or improvements in some characteristics; and (*ii*) improvement in fibre properties of the linted species by employing lintless species in inter-crosses. This suggests that with careful selection, quite a remarkable degree of improvement may be obtained with regard to the existing characters, and other as yet undertermined characters may also be recovered from such hybrids. It is, therefore, necessary to extend the interspecific breeding work beyond the material showing some obvious characters of value.

Cross Compatibility Relationship Between Species. Any comprehensive programme of interspecific hybridisation will have to take into consideration the nature of obstacles met with and the ways and means of overcoming them. As a result of the investigations carried out by several workers, valuable information has been collected on this topic. The known compatibility relationships between the various *Gossypium* species have been presented by Stephens (1945), Brown and Menzel (1952b,c) and Menzel and Brown (1955). Information available on this subject is compiled in Table 29.

It will be seen that many of the cross combinations in *Gossypium* species have not yet been reported on, and from among those reported some have not given viable seeds of fertile offspring. Broad conclusions regarding the interspecific cross compatibility relationships are : (*i*) crosses between the Old World species, excluding some of those involving *sturtii*, produce viable seeds; (*ii*) with the exception of some of the crosses involving *davidsonii* and *gossypioides*, the crosses among the New World diploid species set viable seeds *if fertilization is effected*; (*iii*) in crosses between the New World and the Old World diploid species, excluding a few, fertilization is readily effected but many or all the seeds obtained prove inviable. Incompatibility is then apparently due to some post-fertilization disharmony; (*iv*) tetraploid species hybridise successfully with a majority of the diploid species excluding

Table 29. Cross Compatibility Relationships in Gossypium

Species Male parent: Female parent:	Genoms	*herbaceum*	*arboreum*	*anomalum*	*triphyllum*	*stocksii*	*somalense*	*areysianum*	*sturtii*	*robinsonii*	*thurberi*	*armourianum*	*harknessii*	*klotzschianum*	var. *davidsonii*	*aridum*	*raimondii*	*gossypioides*	*hirsutum*	*barbadense*	*tomentosum*
Diploid: $2n=26$																					
Old World																					
herbaceum	A_1	·	+F	+		+			(+)		±	(—)			(—)	(+)	(+)	±*			
arboreum	A_2	+F	·	+Fm		+S			(+)		±S	(—)			(—)	(+)	(+)	±*			
anomalum	B_1	+	+	·	+F	+	+	+	(—)		±	(—)			+	(+)	(—)	±*		(—)	
triphyllum	B_2				·																
stocksii	E_1			±*		·		+	(—)		(—)	(—)		±*	(—	(—)	—	—			
somalense	E_2					+	·	+													
areysianum	E_3							·													
sturtii	C_1								·	+		+	+			—	(—)	—			
robinsonii	C_2									·											
New World																					
thurberi	D_1								(+)		·	—				±	+F	(—)			
armourianum	$D_{2\text{-}1}$								—		±	·				±	—	—			
harknessii	$D_{2\text{-}2}$										±	+	·					(—)			
klotzschianum	$D_{3\text{-}k}$													·				—			

var. *davidsonii*	D3-d	—	—	+		(—)			(+)		(—)	(—)		+	·	(—)	(—)	(—)			
aridum	D_4								—			—				·	—				
raimondii	D_5					—			—		—	+	—		(—)	—	·	+Fm			
gossypioides	D_6	(—)	(—)	(—)		—			—		(—)	—	(—)	—	—		—	·			
Tetraploid: $2n=52$																					
New World																					
hirsutum	$(AD)_1$	±	±	±		±			+		±	+	+	(—)	(—)	+	+	±*	·	+F	+F
barbadense	$(AD)_2$	±	±	±		±			(+)		±Fm	+Fm	+F	(—)	(—)	+Fm	+	+S**	+F	·	+F
tomentosum	$(AD)_3$																		+F	+F	·

· Self or intraspecific crosses give viable seeds.
— Failure of fertilization.
± Very low success of pollination but viable seeds obtained.
\+ Viable seeds obtained.
* Hybrids died after producing several leaves.
(—) Cross easily but seeds all empty or on germination give inviable seedlings.
(+) Cross easily giving many empty seeds together with a low proportion of viable seeds.
x Semi lethality expressed at about the flowering period.
** Asynaptic.
F Hybrid fertile.
Fm Hybrid only male fertile.
Ff Hybrid only female fertile.
S Hybrid sterile.

klotzschianum and its variety *davidsonii* ; and (*v*) interspecific crosses within the tetraploid group are also readily made.

There are several levels at which hybridisation between two *Gossypium* species may fail (Brown and Menzel, 1952b).

1. Flowers may drop soon after pollination without perceptible enlargement of the ovary, indicating that probably fertilisation did not occur. In *hirsutum*, however, ovaries of emasculated and unpollinated flowers also enlarge for several days before the formation of abscission layers.
2. The ovary may enlarge, and the young boll remain on the plant several days to several weeks ; in these cases fertilization has probably occurred.
3. The bolls may mature and contain either abortive seeds or large empty seeds. In rare instances a hybrid embryo may mature, which may be smaller than a normal one.
4. Hybridisation may fail after the development of an embryo ; the seed germinates, and the seedling dies in the cotyledon stage.
5. Death of seedlings may take place after several leaves are formed ; in some cases plants may even reach the flowering stage.

Methods of Solving the Problem of Species Barriers.

(*i*) *Improving Fertilization* : In some of the interspecific cross combinations in *Gossypium*, failure of fertilization is noticed (Table 29). Stephens (1945) has suggested that in certain crosses simple mechanical difficulties would be sufficient to prevent foreign pollen tubes from reaching the ovules. For instance, *thurberi* pollen tubes would have to travel two to three times the normal distance to reach the ovules of *raimondii*, quite apart from any chemostatic considerations. He has also pointed out that the flowers of the wild species tend to absciss very easily, a tendency which is no doubt enhanced by the handling of the flowers during emasculation. Cross combinations that fail solely due to such mechanical hindrances to fertilization are considered to be potentially compatible, provided that suitable means are devised to overcome the hurdles. Stephens (1945) has remarked that methods of improving fertilization artificially should be worth investigation.

(*ii*) *Embryo Culture* : Some of the cross combinations show post-fertilization incompatibility. An examination of the bolls formed from such difficult or unsuccessful crosses reveals a non-parallel development of embryo, seed coat and capsule which is indicative of a fundamental disharmony between the hybrid zygote and the surrounding tissue. According to Brown and Menzel (1952b), the physiological processes responsible for the development of the different parts of the boll are interrupted at different thresholds, so that the development of all parts does not cease simultaneously. Some types of seed failure, e.g., mature bolls containing well-developed seed coats without embryos, suggest that once certain thresholds are crossed, the processes

involved may continue more or less autonomously, regardless of the subsequent fate of the tissue which produced the initial stimulus. The precise determination of why and how particular crosses in this category fail must await histological studies. In the cross *arboreum* x *davidsonii*, failure of endosperm leading to the death of the embryo was observed by Stephens and Cassidy (1949). Weaver (1957) carried out embryological studies on the cross *hirsutum* x *arboreum*. He reported that only when either the egg cell was not fertilized or the zygote failed to divide, did hybrid endosperm and maternal tissue develop at a vigorous rate and in a fairly normal manner. This resulted in large embryoless ovules. Usually, however, both the embryo and the endosperm started developing but soon aborted. This abortion was considered to be probably due to a physiological unbalance between the two hybrid tissues or more likely, due to a degenerating effect of the hybrid embryo upon endosperm development. In crosses involving the Old World, the New World and synthetic hexaploid cottons also, the endosperm was the first tissue to show abnormalities (Weaver, 1955a). In crosses of the type low chromosome number female x high chromosome number male, the endosperm made rapid initial growth but degenerated 10 to 20 days after pollination without developing cell walls. The greater the difference in chromosome number, the more rapid the degeneration. The embryo often reached one-fifth the normal size but did not differentiate properly. The maternal tissue developed normally. In the other way crosses (except in hexaploid x tetraploid), the endosperm formed cell walls prematurely after five days whereas embryos grew normally for 10 days. The maternal tissue stopped growth immediately after the endosperm. When the egg cell was not fertilized, the endosperm grew at a normal rate, and a large embryoless ovule was produced. In such cases where normal growth and nutrition of the hybrid embryo is not possible *in vivo*, the embryos can be excised and nursed *in vitro*. Stephens and Cassidy (1949) attempted to nurse an *arboreum* x *davidsonii* hybrid in this way but they failed to obtain a viable plant. This may be due to a general genotypic disharmony between the species concerned (Silow, 1941 ; Stephens, 1945). Where there is no additional problem of genotypic differences, embryo culture has been successful. The hybrids between *hirsutum* and *barbadense* on the one hand and *arboreum*, *herbaceum* and *anomalum* on the other can be made but this involves excising and artificially culturing hybrid embryos (Beasley, 1940).

(*iii*) *Manipulation of Cross Combinations* : Even after the formation of viable seeds, there are several thresholds which must be crossed before a hybrid can be called successful. Some cross combinations (Table 29) show post germination lethality of the hybrid zygotes. This lethality may occur early in the cotyledon stage or later after the production of several leaves, or even a few floral buds. The nature of determinants for lethality involved in different cross combinations will be discussed in the chapter on Genetics.

The existence of both lethal and nonlethal alternatives in hybridisation of *hirsutum* with *arboreum* (Gerstel, 1954) or *barbadense* (Stephens, 1946, 1950a) and of *anomalum* with *stocksii* (Douwes, 1951) raises hopes that compatible combinations may ultimately be found where only incompatible ones are available at present. In some of the cases where direct crosses between two species fail to give a viable and fertile offspring utilization of a third species in the crossing programme may be found useful as in the crosses of *gossypioides* with F_1 (*raimondii* x *thurberi*) or F_1 (*hirsutum-barbadense*) instead of with the individual parental species of these F_1s (Menzel and Brown, 1955).

Some of the interspecific hybrids, such as those within the sections **Hirsuta** or **Herbacea**, are fertile in the first generation but show breakdown in the segregating generations. In such crosses free recombination of parental characters is prevented but the backcross technique has been found useful in breeding into the cultivated types some of the desirable genes from the other species. In many other instances the F_1 hybrids are self sterile. In the F_1 (*hirsutum* x *aridum*) vegetative growth is vigorous but the flower is abnormal and is characterized by the extension of the style and stigma above a reduced corolla which is suggestive of a low degree of incompatibility between the parental species (Skovsted, 1935a ; Brown and Menzel, 1952b). Mass pollination of self sterile hybrids has given in some cases offsprings often through functioning of unreduced gametes, e.g., in the crosses of **Hirsuta** species with **Herbacea** species (Amin, 1940 ; Iyengar, 1945). Chromosome duplication (polyploidy) technique followed by backcrossing has proved more useful with such hybrids.

Hybrids of Old World cultigens with some of the New World diploid species have been obtained (Table 29). With regard to such cross combinations including those of the **Herbacea** spp. with *thurberi*, Stephens (1945) has suggested that methods of improving fertilization artificially should be worth investigation. Direct interchange of genes between these two groups of species is not possible because their chromosomes are dissimilar and as such show little pairing during meiosis. The genom (B) of *anomalum* is reported to show part homologies with the genoms A and D of the Old World cottons and the New World diploid species, respectively. Deodikar (1947) has, therefore, suggested that the transfer of desirable genes from the D genom species to the A genom species could be effected in some cases, by using *anomalum* as a bridging species. A complex cross of allotetraploid (*arboreum* x *stocksii*) with F_1 (*raimondii* x *gossypioides*) is reported to set seeds (Brown and Menzel, 1952c). The potentialities of such hybridisation programmes in the improvement of the Old World cottons need to be explored.

(*iv*) *Use of Polyploids* : The New World cultigens comprise the A and D genoms ; species possessing similar genoms are, therefore, considered to offer the most promise in their improvement. Some of the direct hybrids of the

New World cultigens with the Old World or New World species have been used in cotton breeding. Other methods making use of induced polyploids are listed below (see Brown and Menzel, 1952a ; Knight, 1955).

1. F_1 (Autotetraploid of a **Herbacea** species x a **Hirsuta** cultigen) mass pollinated with a **Hirsuta** cultigen.
2. Allotetraploid (a **Herbacea** species x a New World diploid species) crossed with a **Hirsuta** cultigen.
3. Allohexaploid (a **Hirsuta** cultigen x a **Herbacea** species) crossed with a **Hirsuta** cultigen or a New World diploid species.
4. Allohexaploid (a **Hirsuta** cultigen x a New World diploid species) crossed with a **Hirsuta** cultigen or a **Herbacea** species.

The first of the above four methods ensures ready crossing between the **Hirsuta** and **Herbacea** species. The F_1 hybrids obtained by the third and fourth methods are not uniform in their A and D genom composition, respectively. Selection in such crosses, therefore, should begin in the F_1 generation for which a large population would be necessary. These hybrids as well as those obtained by other methods show certain irregularities in chromosome behaviour during meiosis. Menzel and Brown (1954) have commented on their probable role in breeders' material. They state that: (*i*) the A genom translocations may persist, unless intentionally selected against, especially if selection for high fertility has not been the main objective; and (*ii*) some of the duplication-deficiency gametes from the A genom translocations may be functional. The existence and significance of these translocation heterozygotes and the deficiency duplication types in actual breeding stocks remains to be verified; if present, they may have considerable bearing on some of the complications that arise in the breeding work. It is not yet possible to estimate how much the genom translocations interfere with fertility in the derivatives, but it is likely that they reduce it to some extent, both through non-disjunction and by retaining large unbroken blocks of species foreign material. In many instances where the primary intention has been to introduce into *hirsutum*, characters from the New World wild diploid species, the A genom translocations should not interfere with the work. Other irregularities such as the fairly high frequency of excess multivalents deduced to be due to chiasmata between chromosomes of the A and D genoms may, however, interfere with such interspecific transfer of characters. Assuming that they represent cross-overs, such chiasmata can give rise, in backcrosses to *hirsutum*, to a variety of cytological aberrations, including new reciprocal translocations between the A and D genom chromosomes; and possibly also to insertions of the D genom chromosome segments into the A genom chromosome or *vice-versa*, where, with continued backcrossing to *hirsutum* (in which A-D pairing does not occur, at least so frequently) they may become 'trapped' and difficult to alter or eliminate by crossing over. Menzel and Brown (1954) conclude that all such meiotic irregularities may primarily be of nui-

sance value for practical breeding purposes. In this regard it would be of importance to know how quickly they may be eliminated without also eliminating the species foreign characters which it is desired to retain.

Further, allohexaploids containing, in addition to the A and D genoms, B, C or E genoms, have been synthesized. As the B genom is partly homologous with both the A and D genoms, exchange of genes can occur between all these genoms in the hexaploid (*hirsutum* x *anomalum*). By backcrossing such a hexaploid to *hirsutum*, Deodikar (1949, 1950) obtained 'alien (chromosome) substitution and addition' races. These races are useful for transferring *anomalum* genes to *hirsutum* because they enable the breeder to avoid most of the economically undersirable wild characters except those located in the transferred chromosomes. Nearly all the possible synthetic allohexpaloids of *Gossypium* and their inter-crosses have been studied by Brown and Menzel (1952a). The chief interest in the study of the hexaploid cross combinations lies in the demonstration that at least some chiasmata may form between the chromosomes of any two of the five genom groups, A,B,C,D and E in the genus, even between those groups that are most distantly related. It may, therefore, be assumed that exchange of chromatin is *cytologically* possible among all genom groups, even though the exchange in many cases may be limited to parts of only a few chromosomes of the complement. Interspecific transfer of chromatin is, of course, severely limited by the fertility of hybrids in which such exchanges occur at meiosis, as well as by numerous other practical considerations. Brown and Menzel (1952a) have concluded that "at least some of the genic material of species in every diploid genom group of the genus is theoretically available for transfer, directly or indirectly, into the cultivated cottons."

Concluding Remarks. Experience with interspecific breeding in *Gossypium* has been reviewed by Richmond (1951), Sikka (1957) and Joshi and Hardas (1958) in recent years. The need for paying careful attention to the following points in this work has been brought out by several workers.

1. Determining, by histological studies, why and how certain species crosses fail.
2. Devising ways and means of effecting the crosses known to be difficult or impossible to make.
3. Artificially nursing the weak or immature hybrid embryos.
4. Bypassing lethality or sterility of species hybrids by making suitable cross combinations of the species and the synthetic alloploids.
5. Irradiating the species hybrid material at some stage for bringing about deletions and translocations in the chromosomes that may result in elimination of unwanted characters or character combinations (as in the case of a wheat—*Aegilops* hybrid: Sears, 1956).

Richmond (1951) has remarked that although such a programme of work

is undoubtedly of long duration, the future requirements of cotton industry to meet competition in textile trade and to facilitate further technological advances in production and processing, are likely to be such that they can be met, if at all, only by resorting to distant hybridisation.

BACKCROSSING

This is a very useful technique much used in plant breeding work. It has the great advantage that it makes possible the introduction, into commercial varieties, of desirable characters from species and varieties which are otherwise undesirable and could not be made use of in straight hybridisation. This is especially valuable when economically important characters, such as resistance to various diseases and pests are not present in the cultivated varieties but can be found in related wild species. In the backcross programme of breeding an otherwise agronomically acceptable commercial variety or improved type (backcross parent or recurrent parent), which it is intended to improve further in respect of a character or two, is crossed with a variety or strain (donor parent) from which the desirable attributes are to be obtained. The hybrid is repeatedly backcrossed to the backcross parent. The ease with which this technique can be exploited depends on whether the character to be transferred is inherited oligogenically (major genes) or polygenically. In the former case, the procedure is straight forward if the character is dependent on a single dominant gene; when it is recessive, the heterozygotes need to be marked out by selfing or test-crossing. When several oligogenes are to be transferred from one variety to another it is usually advisable to transfer them separately and then bring them together by inter-crossing the different backcross lines (convergent improvement). When two linked factors are to be transferred, it is advisable to select cross-overs in the first backcross progeny as parent for further backcrossing. At times undesirable genes may be so closely linked with the gene it is intended to transfer that they cannot be eliminated without losing also the desirable gene. This situation may defeat the backcrossing programme. When the desirable character is polygenically inherited, the breeder should select in the first backcross plants showing the maximum effect of the character required for further backcrossing.

Harland and Pope (1922) are recognised as being the first to exploit this technique in plant breeding, although Ware (1936) refers to this method having been employed by John Griffin in the U.S.A., as early as 1867, in the production of the cotton variety, Griffin. Harland is generally recognised as the pioneer in applying the technique of repeated backcrossing to cotton breeding. Knight (1945) has recorded his experience of inter- and intra-specific backcrossing over a number of years and has made useful practical suggestions for the exploitation of this technique in cotton improvement.

He has emphasised the need for keeping the backcrossing up-to-date by using, each season, the latest sub-strain of the parent variety used for backcrossing. Another suggestion is that the hybrid should be used as the male parent and the backcross parent (recurrent parent) as the female. This enables the detection of any self-bred plants in the progeny. Moreover, each flower from the hybrid can be used to pollinate about 10 prepared flowers on the backcross parent, and it is possible to grow at least two generations per year because the hybrid plants need only produce pollen which can be used on well established 'mother' plants of the backcross variety. Where a large number of visible differences exist between the original parents, these provide a valuable basis for selection. In such a case large early backcross progenies should be grown and severe selection in the field utilised to accelerate the removal of the donor parent genotype. With few visible differences between the parents, it is advisable to grow small backcross progenies and to concentrate on the elimination of the donor genotype by making as many backcrosses per year as possible. Selection of hybrid plants for further backcrossing should be made solely on : (*i*) presence of transferred gene; and (*ii*) vegetative similarity to the backcross parent. All characters likely to be due to heterosis should be avoided, e.g., longer lint or higher yield than the backcross parent. An arbitrary end-point, i.e., the stage at which to cease backcrossing, should be avoided. For, in cotton breeding, not only must the yield be watched, but also properties like plant vigour and ginning outturn, length, strength, fineness, feel and lusture of the lint. The criterion should be a replicated test of bulk seed from heterozygotes from the backcross, against bottom recessives from the backcross, against the backcross parent as control. When the heterozygous bulk is qualitatively and quantitatively equal to the backcross parent, bulk propagation and large scale testing should be started.

Thomas (1952) has reviewed in detail the results obtained in cotton breeding through the application of the backcross method, which has been widely used in India as well as abroad. By this means not only have genes governing morphological characters been transferred from one species to another (Thomas, 1952), but the technique has been useful in breeding for several economic characters such as ginning outturn, fibre quality and resistance to diseases and pests.

BREEDING FOR RESISTANCE TO PESTS AND DISEASES

A susceptible variety of cotton, heavily attacked by a particular disease or pest, is grown together with the experimental material when breeding for resistance to it. Where natural attack is inadequate, suitable measures are taken for the artificial spread of the hazard. Breeders thus make a deliberate use of the principle of survival of the fittest, in addition to employing the diverse

breeding techniques. Cotton breeders have reported some remarkable achievements in this direction (Thomas, 1952).

Jassid Resistance. In India, natural attack of jassids is particularly excessive on irrigated *hirsutums* grown in Bellary district of Mysore State. Jagannatha Rao, Raghavan and Appa Rao (1952, 1953) have reported on the progress of breeding work for resistance to this pest in the region. They grouped the experimental plants into four categories according to the percentage of leaves that blighted due to the infestation. A reselection 1821, isolated from *hirsutum*—**Herbacea** species hybrid material, proved highly resistant to jassids ; it, however, proved very susceptible to blackarm disease.

Two jassid-resistant varieties of *hirsutum* have been used in crosses with Sudan Sakel (*barbadense*) to build up similar resitance in the latter cotton. Of the two *hirsutum* types one was Indian, M. U. 8b. (Malwa Upland). Its jassid resistance was shown to be due to the presence of long and dense hairs on the abaxial surface of the leaves. In crosses with *barbadense*, the character appeared to be governed by a major gene, $\mathbf{H_1}$ and some intensifying genes ; minor genes as distinct from the intensifiers were of little account (Knight, 1952). The principle adopted for the transference of M. U. 8b hairiness of the full parental length and density into Sakel has been described by Knight (1956). M. U. 8b was crossed with Sakel. Maximum hairiness was selected in F_2 and backcrossed to Sakel. Maximum hairiness was again selected in the F_2 of the backcross for further backcrossing and selfing. Meanwhile, the key gene $\mathbf{H_1}$ was transferred to Sakel backcross by backcross without selfing out until later. As soon as this transference had gone through four to five backcrosses, a homozygous line was selfed out. Hairs in the $\mathbf{H_1}$ $\mathbf{H_1}$ Sakel so produced were too short ; it was, therefore, substituted for the glabrous Sakel as backcross parent in the transference of full hairiness complex into a type retaining the accepted Sakel qualities unadulterated.

The other *hirsutum* type, Ferguson used in crosses with Sakel for breeding jassid resistance into the latter was from the Philippines. It possessed hairs of excellent length and reasonable density on the underside of its leaves. Genetic control of the character appeared to be similar to that in M.U. 8b except that $\mathbf{H_1}$ was inseparably linked with one of the complementary lethals for chlorophyll deficiency $\mathbf{chl_1}$ and that minor hairiness genes with direct effect on the character were of comparatively greater importance (Knight and Sadd, 1954). Knight and Sadd (1954) inferred from their findings that positive length modifiers and negative density modifiers exist in Ferguson. Owing to $\mathbf{H_1}$ — $\mathbf{chl_1}$ linkage in this variety, transference of its hairiness to Sakel by a procedure similar to that followed in the case of M.U. 8b could not lead to isolation of pure lines. For this reason crossing of Ferguson was switched to a Sakel line carrying $\mathbf{H_1}$ from one of the other available sources. The favourable complex of minor hairiness genes in the

Philippine variety was transferred in this way to **H₁ H₁** Sakel background instead of being kept with its own **H₁** (Knight, 1956).

The reaction of jassid-resistant Sakel to some other pests has been studied by Pollard and Saunders (1956). Since, white-fly, aphids and mites show increase on hairy plants, these workers emphasize the need for producing jassid-resistant types without increasing their susceptibility to other pests.

Pink Bollworm Resistance. McDonald, King, Munro and Wickens (1948) have described the procedure employed by them for ensuring a heavy attack of pink bollworm in their experimental material. A *hirsutum* cotton susceptible to the pest was sown in six acres of land beside the test plot some eleven weeks before the experimental material was planted. By the time the latter material flowered freely, the *hirsutum* sown earlier was heavily attacked by bollworm. The latter was then cut and left lying beside the test plot and in addition infested bolls were broadcast in the test plot.

Despite several attempts made by the cotton breeders to incorporate pink bollworm resistance of *thurberi* in the New World cottons, a limited success has been reported only by Knight, Dark and Cuany (1953).

Thrip Resistance. Heavy attack of thrips on *hirsutum* cottons grown in Vidarbha tract of Bombay State and in the Punjab has been reported recently (Paranjpe, 1958). Preliminary investigations carried out by Paranjpe (1958) show that 'Cotom' strains isolated from *hirsutum-tomentosum* hybrid will be of great use in evolving thrip-resistant *hirsutum* strains in India.

Fusarium Wilt Resistance. The method of breeding for wilt resistance in *arboreum* and *herbaceum* cottons in India originally consisted of growing the different varieties of the crop in a field in which the naturally occurring wilt infection was very heavy and selecting the promising plants that survived the attack. Such selections repeated over a period of years led to the isolation of wilt-resistant pure types. Variations in soil infestation and seasonal climatic changes, however, rendered the selection of resistant types in this way highly unreliable. Uppal (1938) stressed the importance of evolving wilt-resistant strains of cotton only under optimum conditions of infection. According to him, wilt resistance in cotton is affected in its expression by three important factors: (*i*) degree of soil infestation by the pathogen; (*ii*) soil temperature (optimum range *c.* 25° to 27° C.); and (*iii*) atmospheric temperature (optimum range *c.* 26° to 30°C.). Assuming uniformly severe soil infestation, adverse aerial or soil temperatures can induce temporary resistance in plants of a susceptible type resembling the inherited resistance shown by the immune variety even at optimum temperature conditions. The technique evolved by Uppal (1938) for the production of wilt immune cottons takes into account all these factors. A highly susceptible variety is grown year after year on a wilt infected plot so as to intensify the infection. Young stalks of a susceptible cotton type are chopped with wilt infested ones.

To these choppings are added large quantities of wilt culture grown on cotton seed meal in giant Erlenmeyer flasks. Wilt compost prepared in this way is spread over the surface of the wilt sick plot and harrowed into the soil. Experimental material is first tested for wilt resistance in such a plot. Seeds collected from the surviving plants are further tested in pot culture. The pots are filled with steam sterilized mixture of one part compost manure and two parts soil. Wilt culture reared on Richard's solution is added to each pot and kept for a fortnight before sowing the seeds. The plants to be tested for wilt resistance are reared in these pots in a glasshouse where temperature ranges from 25° to 28°C. The plants that survive this rigorous test are considered wilt immune.

The percentage mortality of plants under optimum conditions for the *Fusarium* wilt has been determined for some of the *arboreum* and *herbaceum* cottons of India. The available information is given in Table 30.

It will be seen from Table 30 that breeding for *Fusarium* wilt resistance in cotton has proved very successful in different tracts of India.

Ramiah and Paranjpe (1947) have described the actual field procedure followed in breeding for wilt resistance in Malwa tract. Replicated progeny row trials were conducted always in duplicate, one in the wilt sick plot and the other in the wilt free plot. The trials with F_3 to F_5 generations of the cross that proved most promising with respect to wilt resistance in the F_2, comprised about 90 progenies each time and by F_4 variation within families was considerably reduced. The first small bulk trial was undertaken in F_5. The Swalöf technique of making repeated selection of plants for disease resistance and other desirable attributes and growing them as bulk for two or three seasons (up to F_4) was also made use of. Subsequently (from F_5) the replicated progeny row technique was practised for this material.

Bacterial Blight (Blackarm) Resistance. Kaiwar, Pise and Allayannawarmath (1955) have reported that Indian *herbaceums* on the whole suffer the least due to this disease. Next in order of increasing susceptibility come the *arboreums* whereas the New World cottons in India suffer the most due to this disease.

Blackarm disease is reported to be a serious hazard for the *hirsutum* cottons grown particularly in Mysore State in India. Laxmi cotton is most susceptible to this disease. Since seed treatment was found to be of little use as a control measure, Kaiwar and Allayannawarmath (1956) concentrated on evolving resistant varieties. The first thing to be done in breeding for disease resistance is to find a means of giving the experimental plants a heavy and equal dose of the disease. This was ensured by Kaiwar and Allayannawarmath (1956) in the following way at Dharwar, Mysore State.

1. The cotton was grown in a plot of land for some years during the successive seasons without intercalating any rotational crop. The

Table 30. Fusarium Wilt Mortality in Different *arboreum* and *herbaceum* Cotton Types of India under Optimum Conditions for the Pathogen

Species, Tract, State and Variety	Wilt mortality per cent. (approx.)	Reference
G. arboreum		
Khandesh tract :		
Bombay State		
Local original (Jadi Mixture) ..	60	Khadilkar, 1947b
Jarila	2	,,
Virnar	2	,,
Gaorani tract :		
Bombay, Mysore and Andhra Pradesh States		
Gaorani 6	100	Bederker, 1956
1494	13	,,
1422	16	,,
Mathio tract :		
Gujerat—Bombay State		
Mathio local	91	Phadnis, 1957
Pratap	92	,,
C. J. 73	68	,,
Malwa tract :		
Madhya Pradesh		
Malvi 9	85-90	Merh, 1956
Bhoj	12-13	Simlote and Merh, 1955
G. herbaceum		
Gujerat :		
Bombay State		
1027A L. F.	100	Phadnis, 1957
Vijalpa	(Wilt-resistant)	Pandya, Majumdar and Desai, 1956
Kumpta tract :		
Mysore State		
Kumpta local	41	Tippannavar and Patil, 1952
Dharwar 1	50	,,
Dharwar 2	2	,,
Jayawant	6	,,
K. F. T. 12-2-5	Nil	,,
Jayadhar	Nil	,,

infected plant parts that fell in the field from year to year helped the recurrence of the disease every year.

2. The blackarm infected plant parts were finely powdered and mixed with sand. This mixture of additional inoculum was drilled into the soil of the already infected plot, a week prior to sowing the experimental material.
3. A decoction of the bacterial inoculum was prepared by soaking infected leaves in water for about two hours. The seeds were soaked in this decoction for two hours before planting them into the sick plot.
4. Pure cultures of blackarm were multiplied for 8 to 10 days on 250 c.c. lots of Peptone Dextrose broth, each contained in a 1,000 c.c. Erlenmeyer flask. Culture from each flask was added to two gallons of water. Inoculum thus prepared was sprayed on the plants in the infected plot. In all four sprays were given, two during first three months and two more during the subsequent two months.

The second important item in breeding for disease resistance is grading of plants according to their reaction to the pathogen. In the Sudan, Knight and Clouston (1939) and Knight and Hutchinson (1950) classified their reactions into 13 grades depending upon frequency, size and form of lesions on the Old World cottons and on size and form of lesions on the New World cottons. In the U.S.A., Simpson and Weindling (1946) grouped these grades into three main classes: highly resistant, tolerant and susceptible. At Dharwar in India, Kaiwar and Allayannawarmath (1956) graded the infected plants into seven categories which were merged into four main classes: immune, resistant, mildly susceptible and susceptible. The initial grading for the intensity of blackarm attack on the experimental material was begun immediately after the second spray of inoculum. The final grading was done after the fourth spray. At Dharwar, breeding for blackarm-resistance in *hirsutum*, in this way has led to the isolation of practically immune progenies from the interspecific combination of *hirsutum* with one of the **Herbacea** species (Kaiwar and Allayannawarmath, 1956). At Coimbatore in Madras State, Balasubrahmanyan and Raghavan (1950) had reported isolation of Cambodia (*hirsutum*) strains resistant to the bacterial blight by reselection under conditions of artificial infection. At Siruguppa in Mysore State, the natural incidence of blackarm is very heavy. Jagannatha Rao, Raghavan and Appa Rao (1952, 1953) reported the isolation of a blackarm-resistant strain, 2196 (a derivative from the cross, *hirsutum* x a **Herbacea** species) at this station. It, however, showed susceptibility to jassids.

From the U.S.A., Bird and Blank (1951) reported the transference of bacterial blight resistance of Stoneville 20 (*hirsutum*) to commercial *hirsutums* of Texas. They sprayed the experimental material with the inoculum during

the early part of growing season. A satisfactory degree of blight resistance was expressed following one or two backcrosses to the recurrent parent.

In the Sudan, Knight and his associates sprayed a collection of over 1,000 types belonging to the New World and the Old World cottons with blackarm inoculum and studied their reactions (Knight and Hutchinson, 1950; Knight, 1954a,b, 1956). They have surveyed the available sources for blackarm resistance in cotton and have studied critically the inheritance of the character. The genetic investigations were carried out in the firm belief that an economical and effective solution of the breeding problem was only possible on a foundation of this knowledge. Altogether nine blackarm-resistant genes have been reported to exist, of these $\mathbf{B_2}$ and $\mathbf{B_3}$ *ex hirsutum* race *punctatum* and $\mathbf{B_{6m}}$, an intensifying gene, *ex arboreum* have been found most useful when transferred to Sudan Sakels (*barbadense*). $\mathbf{B_2}$ alone gives fair resistance; $\mathbf{B_2} + \mathbf{B_3}$ confer high enough resistance which shows partial break-down in wetter tropics; $\mathbf{B_2} + \mathbf{B_{6m}}$ impart field immunity to the stem, leaf and boll forms of the disease; and $\mathbf{B_2} + \mathbf{B_3} + \mathbf{B_{6m}}$ give immunity (Knight, 1954a, 1956). The transference of $\mathbf{B_{6m}}$ from *arboreum* to *barbadense* was effected step by step. Induced autotetraploid of *arboreum* was first crossed with (Sakel) *barbadense*. The resulting hybrid, though self sterile, set some seeds on being mass pollinated by *barbadense*. The backcross plants were employed in the regular back-crossing programme and selections were made under conditions of artificial epiphytosis for blackarm.

Knight and Hutchinson (1951) have pointed out that effective resistance to bacterial blight can only be built around a main gene. $\mathbf{B_2}$ is the basis of all worthwhile resistance in *hirsutum* and it has spread from the race *punctatum* to Upland crops (race *latifolium*) of the Old World. Minor gene intensification of the effect of $\mathbf{B_2}$ is reported by these workers to be of common occurrence in India. The value of $\mathbf{B_2}$ and $\mathbf{B_3}$ has been doubted by Balasubrahmanyan and Raghavan (1950) since cotton varieties known to be blackarm resistant in the Sudan did not necessarily show resistance in tests carried out at Coimbatore in Madras State. It was suggested that the genes $\mathbf{B_2}$ and $\mathbf{B_3}$ may confer resistance only under particular climatic conditions, or alternatively, that they are only effective against certain biologic strains of the pathogen. If this be so, difficulties in breeding for blackarm resistance in cotton would be further augmented.

Red Leaf Blight Resistance. Upland and *barbadense* cottons in India suffer from a serious malady whose chief external feature is a reddening of leaves accompanied by an upset of the photosynthetic activity. This malady is variously known as red leaf of American cotton, red leaf blight and blight (Gopala Iyengar and Srinivasa Iyengar, 1956). At Dharwar in Mysore State, breeding specifically for resistance to this disease was undertaken. Gadag 1 showing about 97 per cent. susceptibility to the malady was crossed

with a resistant type from Madras State, Co. 2. The type Laxmi isolated from this cross shows 75 per cent. resistance to the malady (Tippannavar and Patil, 1952).

Leaf Curl Resistance. Leaf curl of cotton is caused by a virus. Knight (1954b) has reported that resistance to this disease depends on a number of genes with very small individual effect but a carefully planned system has made it possible to build, in the Sudan, resistant strains of Sakel (*barbadense*) from susceptible varieties in a few generations. Two or three acres of a blackarm-resistant Sakel are sown plentifully interspersed with transplanted leaf curl infected cotton plants. Alongside this plot is sown an acre of *lubia* a legume on which white-fly breed rapidly. When the *lubia* (*Dolichos*) has developed a large population of these insects it is cut in order to drive the white-fly on to the cotton. Here the flies feed freely on healthy and diseased plants alike and they soon start spreading the disease. All the weak infested plants (90 to 95 per cent.) are pulled out; it is assumed that the remainder show some degree of resistance. These are allowed to inter-cross so as to build up still higher levels of the minor genes governing resistance. The process is repeated for two to three generations when a high leaf curl resistance is built up in strains retaining the desirable lint quality identical with that of the parent varieties.

HETEROSIS

In cotton, it was Mell (1894) who first observed an increase in fibre length and agronomic characters in the F_1 hybrid of *G. hirsutum* with *G. barbadense*, as compared to the parents. Cook (1909) was the first to suggest the possibility of economic exploitation of this hybrid and recommended the production of hybrid seed by means of hand pollination or by the use of insect pollinators, and the further propagation of the hybrids by vegetative means. Since then hybrid vigour in cotton has been observed by many workers in interspecific hybrids involving the various diploid and/or tetraploid species of cotton (Kearney, 1923b; Ware, 1930, 1931; Jenkins, Hall and Ware, 1939; Vysotskii, 1932; Ayers, 1938; Kelkar, Choudhary and Hiremath 1947a; Koshal, Gulati and Ahmad, 1940; Ramiah, 1944; Santhanam, 1951; Patel and Patel, 1952; Bhat and Kaiwar, 1955; Ganga Prasad Rao, 1956; Pandya and Patel, 1958b), and by some workers in intraspecific hybrids (Kearney and Wells, 1919; Patel and Patel, 1927; Brown, 1927, 1942; Ayers, 1938; Hutchinson, Panse and Govande, 1938; Jenkins and Harrel, 1941; Ramiah, 1944; Kelkar, Choudhary and Hiremath, 1947a; Kelkar and Kaiwar, 1947; Kime and Tilley, 1947; Simpson, 1948; Mikailow, 1950; Govande and Joshi, 1950; Jones and Loden, 1951; Turner, 1953; Harris and Loden, 1954; Bederker, 1958). Loden and Richmond (1951) have presented a detailed account of the work on hybrid vigour in cotton.

Table 31 summarises the information relating to agronomic characters in respect of which heterosis has been reported in interspecific hybrids involving the cultivated species of *Gossypium*.

The extent of vigour of the hybrid depends on the genetic diversity between the parents used for crossing. A survey of heterosis in cotton indicates that, while interspecific hybrids almost invariably manifest considerable hybrid vigour, intra-specific hybrids exhibit such vigour to a marked extent only in certain combinations, especially in hybrids made between geographically distinct varieties or races of a species (Ayers, 1938; Jenkins *et al.*, 1939; Kelkar *et al.*, 1947a; Bhat and Kaiwar, 1955) and occasionally so in the case of crosses made between varieties within a region (Bederker, 1958).

Work done in the Deccan India has indicated that the *hirsutum-barbadense* hybrid is commercially exploitable in certain cotton tracts if the hybrid crop is adequately manured and irrigated and protected against pests and diseases. Pilot projects are underway in Bombay State to cultivate this hybrid on a limited scale on the cultivators' field for assessing its commercial value. For the cotton tracts in northern India, the *hirsutum-barbadense* hybrid is too late to be usefully productive. Some intra-*hirsutum* hybrids have given good performance in Mysore State. Upland (Gadag 1) x Cambodia (Co.4) hybrid yielded nearly twice as much as Gadag 1 and showed 2.1 per cent. improvement in ginning outturn and 3·8 mm. increase in staple length over the superior parent (Kelkar and Kaiwar, 1947). Bhat and Kaiwar (1955) have reported that the inter-racial hybrid of Cambodia type, M.C.U. 1 (race *latifolium*) with Quebradinho (race *marie-galante*) is suitable for cultivation in waste lands and grass lands or even in new areas of Mysore State coming under Tungabhadra and Ghatprabha irrigation projects. In Gaorani tract of Bombay State, Bederker (1958) has indicated the practical possibilities of stepping up the low yield of Gaorani cotton (*arboreum*) by making use of the inter-strain hybrid, 1946 x M.980.

The commercial production of hybrid seed in cotton presents certain difficulties. Male sterile lines, which could facilitate the work, are not yet available in this crop. The extent of natural crossing in cotton in India is too little for this method to be useful in the production of hybrid seed. The hand pollination method is rather expensive, apart from the fact that it would take large bands of well trained labourers to do this work if genuine hybrid seed is to be produced. In India, the cost of hybrid seed produced this way has been estimated to range from Rs. 3 to Rs. 21 per pound (Balasubrahmanyan and Narayanan, 1948; Patel and Patel, 1952; Thakar and Sheth, 1955; Kaiwar and Kubsad, 1957).

If the commercial cultivation of hybrid cotton is to become a reality anywhere, the first consideration is that what the hybrid offers the grower and the industrialist, especially in respect of yield and fibre quality, must be something

TABLE 31. SOME PLANT CHARACTERS IN RESPECT OF WHICH HETEROSIS HAS BEEN REPORTED IN F_1 HYBRIDS OF INTERSPECIFIC CROSSES IN COTTON

Character	Investigators working with crosses between		
	Old World species (*arboreum-herbaceum*)	New World species (*hirsutum-barbadense*)	Old World and New World species*
Yield	Kelkar, Choudhary and Hiremath (1947a); Santhanam (1951)	Mell (1894); Cook (1909); Kearney (1923b); Kulkarni (1927); Balasubrahmanyan and Narayanan (1948); Santhanam (1951); Patel and Patel (1952); Fikry (1953); Bhat and Kaiwar (1955); Thakar and Sheth (1955)	
Lint length	Kottur (1923); Kelkar, Choudhary and Hiremath (1947a); Santhanam (1951)	Mell (1894); Balls (1908); Cook (1909); Harland (1915); Kearney (1923b); Kottur (1925); Thadani (1925); Ware (1930); Balasubrahmanyan and Narayanan (1948); Santhanam (1951); Patel and Patel (1952); Fikry (1953)	
Ginning outturn	Kottur (1923)		
Seed index		Balls (1908); Ware (1930)	
Plant height	Santhanam (1951)	Mell (1894); Balls (1908); Kearney (1923b); Ware (1930); Ayers (1938)	Feng (1935)
General plant growth	Fyson (1908)	Cook (1909); Kearney (1923b); Ware (1930); Vysotskii (1932)	Zaitzev (1925); Desai (1927); Harland (1932b); Nakatomi (1931); Feng (1935)

* These hybrids are self sterile and, therefore, economically useless.

out of the range of the cotton varieties under cultivation, apart from the fact that genuine hybrid seed must be within the reach of the grower and its cost must suit his pocket. Such a stage does not seem to have as yet been reached anywhere, although the *hirsutum-barbadense* hybrid has at present attracted some attention in India because of the country's need for stepping up the indigenous production of long and extra-long staple cottons.

BOMBAY STATE: Patel and Patel (1952) first reported that the F_1 hybrid of Cambodia *hirsutum*, Co.2 with the *barbadense* type, Sea Island V.135 proved particularly high yielding (1,401 lb. of seed cotton per acre) in Kaira district of Gujerat tract (Bombay State). The lint obtained could be spun to 80's warps. The hybrid crop, being susceptible to jassids and pink bollworm, needed protection against those pests. Thakar and Sheth (1955) recommended the substitution of Co.2 by 134-Co.2-M, a *hirsutum-herbaceum* derivative, in the cross combination because, unlike Co.2, 134-Co.2-M flowered simultaneously with Sea Island and did not shed young bolls under spells of early rains. Pandya and Patel (1958) carried out trials with several *hirsutum-barbadense* combinations and obtained best results with the cross of another derivative from **Hirsuta** cultigen x **Herbacea** cultigen, B.C. 68 with Sea Island. This cross proved the least susceptible to jassids and thrips and highly resistant to blackarm. The only handicap was the pink bollworm attack.

KERALA STATE: The Combodia-Sea Island (*hirsutum-barbadense*) hybrid was tried out on 7·36 acres in Kerala. It gave a mean yield of 525 lb. of seed cotton per acre which was considered very satisfactory for a pilot trial in a non-cotton growing area (Iyengar and Ramaswamy, 1956). Mean fibre length of the produce was 1·26″. It was estimated to spin to 60's.

MADHYA PRADESH: At Indore, 14 extra-long staple *barbadense* types were crossed with the local *hirsutum* type, Indore 2. In the trial for hybrid vigour the hybrid of Indore 2 with the Egyptian cotton, Menoufi proved to be the best in performance (Simlote, 1956).

MADRAS STATE: A variety of cotton from Brazil known as Verdao or Riqueza, probably a derivative of the cross of *hirsutum* race *latifolium* with *barbadense* var. *brasiliense* (Christidis and Harrison, 1955), was hybridised with Cambodia cotton, Co.2. It recorded a yield of 2,210 lb. of seed cotton per acre under rainfed conditions and showed marked increase in staple length (Balasubrahmanyan and Narayanan, 1948). The F_1 hybrids also showed increased resistance to the stem weevil and insects damaging the bolls. They were, therefore, considered to be suitable for growing as perennial substitutes for the pest ridden perennial *arboreum* type, Nadam of Madras State. With the opening of the Lower Bhowani Irrigation Project, however, it has been proposed to grow annual Cambodia (*hirsutum*) cotton as a winter crop in place of the perennial Nadam cotton (Kalyanaraman, 1955).

IMPROVEMENT OF INDIAN COTTONS

There are several cotton breeding centres in India, a majority of which were established during the first two decades of the present century. Systematic selection work carried out at these stations has led to the evolution of a series of types, each showing a distinct improvement over its predecessor in some respect. The superior types have been distributed to the cultivators from time to time and the acreage under these cottons has increased steadily (Table 32). There is a consequent improvement in the quality as well as the productivity of Indian cottons (Tables 33 and 34). It is estimated that cotton growers earned an extra income of over 14 crores of rupees in 1954-55 season alone by growing the improved varieties of cotton (Anon., 1955).

TABLE 32. ASCERTAINED AREA* (PER CENT. OF TOTAL) UNDER IMPROVED COTTON TYPES

Indian Territory		Territories of India and Pakistan	
Period	Area	Period	Area
..	..	1937-42	26·0
..	..	1942-47	53·8
1947-51	48·9	..	..
1953-55	62·8	..	..

*Estimated from the data given in the Annual Reports of the Indian Central Cotton Committee, 1937-56.

TABLE 33. AVERAGE YIELD OF COTTON PER ACRE AS DETERMINED FROM THE OFFICIALLY ESTIMATED ACREAGE AND THE ACTUAL COMMERCIAL PRODUCE RECORDED*

Indian Territory		Territories of India and Pakistan†	
Period (Sept. 1 to Aug. 31)	Yield per acre (lb.)	Period (Sept. 1 to Aug. 31)	Yield per acre (lb.)
.. ..	..	1922-27 ..	96
.. ..	..	1927-32 ..	95
.. ..	..	1932-37 ..	108
		1937-42 ..	109
1939-44 ..	94	1942-47 ..	113
1944-49 ..	92		
1949-54 ..	93	.. ..	..

† Mill consumption of cotton in Burma included up to the 31st March, 1937. Burmese cotton exports up to 1934-35 also included.

* From Annual Reports of the Indian Central Cotton Committee, 1939-56.

TABLE 34. STAPLEWISE PRODUCTION OF COTTON*

Indian Territory				Territories of India and Pakistan		
Period	Produce (per cent. of total) under cottons of staple			Period	Produce (per cent. of total) under cottons of staple	
	Long	Medium	Short		Long and Medium	Short
..	..	..	..	1922-27	30	70
..	..	..	..	1927-32	25	75
..	..	..	..	1932-37	31	69
..	..	..	..	1935-40	34	66
1940-45	17	41	42			
1945-50	17	51	32	..	..	..
1950-55	32	43	23	..	..	..

* From the Annual Reports of the Indian Central Cotton Committee, 1939, 1941 and 1955 (Long=28/32″ or over ; Medium=23/32″ to 27/32″ and Short=22/32″ or less).

Acre yields of cotton have been stepped up not solely by distribution of the improved varieties to the farmers; other measures such as application of fertilizers and manures, extension of irrigation facilities, adoption of improved cultural practices and control of insect pests and diseases have also contributed towards greater productivity of cotton. Figures of average yield of cotton per acre in the territories of India and Pakistan during the period 1922-47 show a marked rise during the quinquennium 1932-37 (108 lb. per acre, Table 33). In these territories, during the period 1927-32 nearly 15 per cent.† of the total area under cotton was irrigated and the average yield of cotton was 95 lb. per acre. A similar level of productivity is shown by the territories of India alone during the period 1939-54, when cotton under irrigation formed only about eight per cent.† of the total cotton acreage. This maintenance of productivity of cottons at a higher level even when area under irrigation is nearly reduced to half, indicates that the yielding capacity of the cotton types under distribution in India at present is improved. It is, however, difficult to assess precisely how much of this improvement is due solely to the genetic improvement of the cotton types. Panse and Sahasrabuddhe (1947), from their statistical appraisal of improvement in productivity of rainfed cottons of India, inferred that "improved seed cannot ordinarily be counted upon as contributing to better yield in cotton, except where strains have been bred for resistance to *Fusarium* wilt."

The production of short staple cottons in the country far exceeded that of long and medium staple cottons up to 1940 but by now the situation is reversed (Table 34). This remarkable shift towards increased production of better staple cottons is greatly due to the varietal improvement effected in the *arboreum*, *herbaceum* and *hirsutum* cottons grown in India. To a certain extent,

† Computed from the data compiled in Agricultural Statistics of India 1927-32 and in Indian Agricultural Statistics 1950-55.

increased cultivation of *hirsutum* cottons has also contributed towards amelioration of the staple character of Indian cotton. Beginning with a very small proportion nearly 50 years ago, the *hirsutums* have now come to form about 25 per cent. of the total cotton produce in the country (Anon., 1956a).

An account of the genetic improvement brought about as a result of breeding experiments carried out in *arboreum*, *herbaceum* and *hirsutum* cottons in India is given in the following pages. Under each species, a general account is followed by notes on the improvement of individual characters such as yield, ginning percentage and fibre qualities.

Some of the above characteristics show seasonal variation. Yield is the most variable character. Besides being governed by the genetic composition of a variety, it is also influenced by seasonal climatic fluctuations, soil fertility and hazards caused by diseases and pests. Data on yield trials conducted with new and preceding cotton varieties at different breeding centres are not available in many cases. In these instances the work of gauging the degree of improvement effected in this character is rendered difficult but data are available from which some indications are obtainable though no statistically sound inferences can possibly be drawn. Some of the Indian cottons, which serve as standards of reference, are being maintained at different breeding centres. They are grown each season from the true seeds and under as nearly the same conditions as possible. Figures for their yields per acre, compiled in the Technological Reports on Standard Indian Cottons and also those published for other types have been used here for gross comparison.

Ginning value is much less subject to seasonal fluctuation. Only under extremely adverse conditions, the ginning value of a variety may be greatly affected. Changes brought about in this character by breeding are inferred from the data published in the Technological Reports on the Standard Indian Cottons and other literature.

The fibre properties dealt with in this chapter are : (*i*) fibre length ; (*ii*) fibre weight per unit length ; and (*iii*) highest standard warp counts. Each of these properties shows seasonal variation to varying degrees. Mean or range values of these properties of the different standard cottons for the entire period of their testing have been considered together with those published for the other varieties in order that the extent of improvement effected in each character could be assessed.

Improvement of Gossypium arboreum Cotton

Cotton belonging to the species *arboreum* forms at present nearly 46 per cent. of the total production in India. The ancient and renowned Dacca Muslin industry probably depended primarily upon *arboreum* cotton. There is no unanimity of opinion regarding the exact type or types of cotton used by the Industry. Ramnathan (1938b) inferred from historical records that the raw material used for the muslins was from an annual form of *arboreum*

of Assam called *photee* whose chief peculiarity was that when it was bleached its fibres did not swell. Fine muslins were prepared from this coarse cotton only after storing it for a year. According to Hutchinson (1938b), a perennial *arboreum* cotton of the Chittagong Hill tract, (now included in Pakistan), was the cotton from which the Dacca Muslins were prepared. The industry probably received finer cottons as well, belonging to *herbaceum* from Gujerat and *arboreum* from Vidarbha tract (both areas now in Bombay State). This conjecture was based on the fact that tests conducted at the Indian Central Cotton Committee's Technological Laboratory and Shirley Institute of the United Kingdom showed that the muslin was made from a cotton which had just about an inch mean staple length and $0 \cdot 12 \times 10^{-6}$ to $0 \cdot 15 \times 10^{-6}$ oz. fibre weight per inch (Ahmad, 1938).

Botanically the *arboreum* cotton in India belongs to three geographical races, *bengalense*, *indicum* and *cernuum* ; some of the types recommended for cultivation are derivates from inter-racial hybrids. In *bengalense* cottons four genetic types are recognised on the basis of petal colour and width of the central leaf lobe ; *verum*—yellow petal, narrow lobe ; *malvense*—yellow petal, broad lobe ; *roseum*—white petal, narrow lobe ; *cutchicum*—white petal, broad lobe. Cottons of the race *bengalense* origin are grown over areas located throughout the country, *indicum* and its derivatives are cultivated in the Deccan and *cernuum* cotton is restricted to Assam Hills and Tripura State. Cottons originating from the race *indicum* comprise both summer and winter varieties.

The various cotton types originating from all the three races of *arboreum* are popularly identified under several trade names. Cotton breeding work, leading to the release of different *arboreum* types for cultivation from time to time, will now be reviewed.

OOMRAS

Cottons of *bengalense* or *indicum* origin, mixed or unmixed with *hirsutum*, grown in Vidarbha tract (Bombay State) are known to the trade as Oomras. The name is derived from the town Amraoti (also spelt as Amaravati or Oomraoti) in this region. Similar cottons of Khandesh tract (Bombay State), Malvi tract (Madhya Pradesh and southern part of Rajasthan), Mathio tract (Bombay State) and Gaorani tract (Bombay, Mysore and Andhra Pradesh States) are also identified by trade as Oomras. All these cottons are grown as summer crops under rainfed conditions. Excepting the Mathio tract, the other areas on which they are grown possess the black cotton soils. In the black soil region, sowings are made during June-July and pickings extend from September to January. The soils of Mathio tract are a coarse loam known by the name of *gorat*. In this region also sowings are made during June-July but harvesting extends from October to December.

Vidarbha and Khandesh Tracts (Bombay State): The original cotton of Vidarbha tract was known as Bani and belonged to the race *indicum*. Under the name of Hinganghat Bani, it had earned a reputation in the Liverpool Market as being the finest Indian cotton (Mahta, 1938). Its displacement by a better ginning mixed type known as Jadi Mixture began in the middle of the last century. This Jadi Mixture originated in Khandesh tract opened up for cultivation for the first time during the British regime. On these lands, freshly cleared of the forests, cottons belonging to *hirsutum*, *herbaceum* and *arboreum* race *indicum* were tried out (Khadilkar, 1947). Race *indicum* alone proved suitable for the tract but was later on given up in preference to the more productive *arboreum* race *bengalense* cottons introduced into the region from the northern cotton regions (Hutchinson, 1938b). Mixture of all these cottons gave rise to what became known as Jadi Mixture, the predominant component of which was *arboreum* race *bengalense*.

Vidarbha Tract : The work on the improvement of cotton for this tract has been reviewed by Bhatt and Shrivastava (1956). Prior to 1922, a selection, Roseum was isolated from the local Jadi Mixture. Considering the trade requirements at that time, attention was paid to ginning outturn only and staple qualities were totally neglected. Thus, type Roseum received a great impetus during the boom period following the First World War. It, however, soon showed wilt susceptibility. Cultivation of Roseum year after year on the same piece of land without any proper rotation led to a rapid spread of the disease, driving many lands out of cotton cultivation. It was thus felt necessary to breed a better quality cotton resistant to wilt. Work on evolution of such a type was begun in 1922. Hybridization work carried out established that the *bengalense* cottons, *malvense* and *verum* owed their wilt resistance to *cernuum* ancestry (Mahta, 1938). In *verum* this ancestory could be detected by observing the outline of the middle lobes of its leaves. The central leaf lobes of *verum* (or *roseum*) are narrow and appear normally like an isosceles triangle in outline ; when either of the borders of these lobes are convex, a *cernuum* ancestry and wilt resistance is indicated (Mahta, 1938). Selection from *verum* led to the isolation of the wilt-resistant type Verum 262 in 1924. This type, however, suffered much under heavy and late rains in the eastern part of the tract. A late *verum* suitable for this tract was, therefore, isolated. Other useful *verum* types isolated were: (*i*) an early one evading drought or frost setting in later in the season; and (*ii*) another doing better than Verum 262 in lighter soils of Buldana and other districts. Efforts made to evolve an all round type culminated in the production of the strain Verum 434 in 1931 by selection from the original bulk cotton. This type was drought and wilt-resistant. It had soft, strong and long lint suitable for spinning up to *c*. 27's H.S.W.C. In spite of its inferiority in yield and ginning outturn as compared to Verum 262, Verum 434 rapidly displaced Verum 262 in the

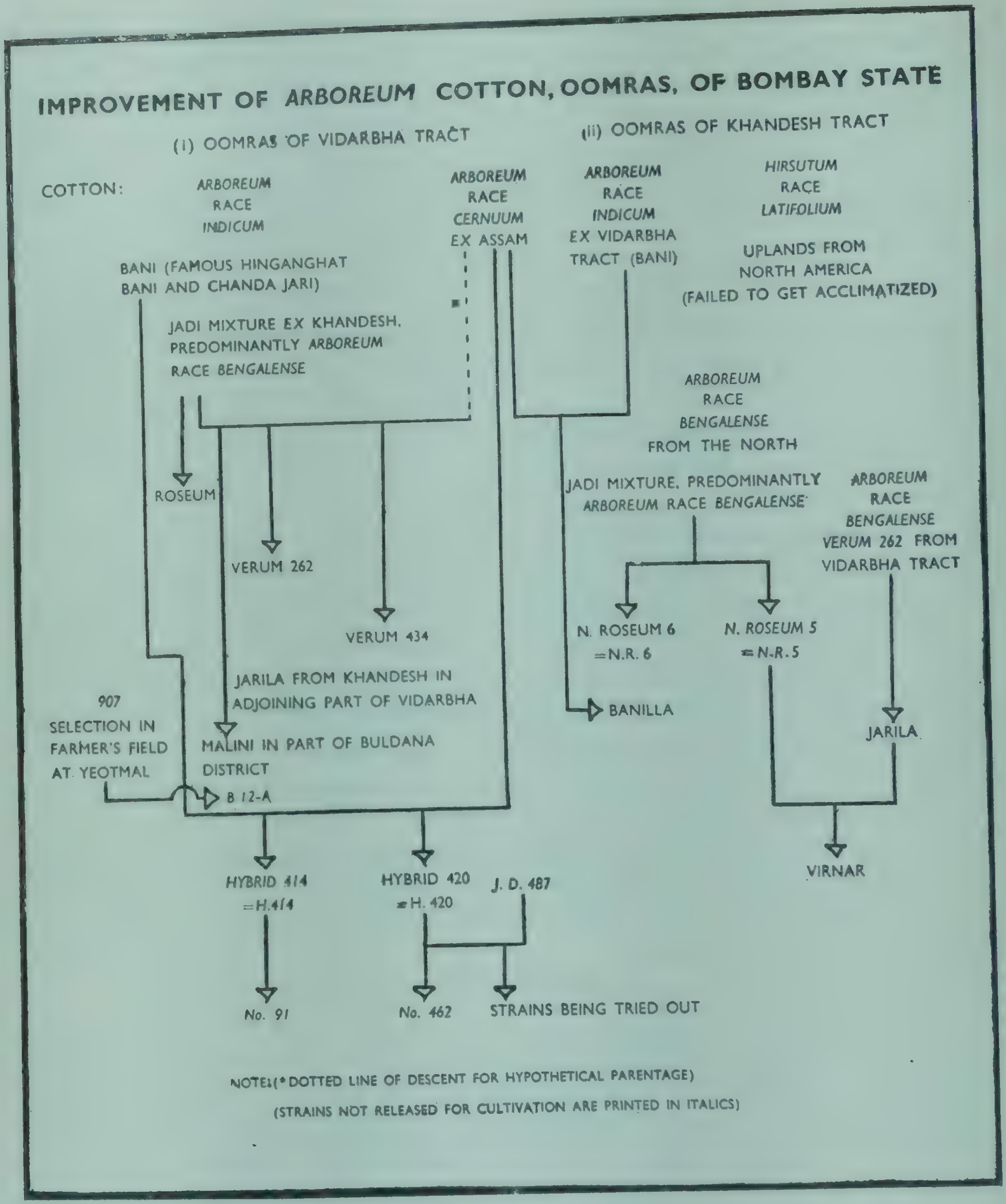


Fig. 19. Improvement of *arboreum* Cotton, Oomras of Bombay State.

region because of its superior quality. Later, Verum 434 in its turn started yielding ground to Jarila (a reselection from Verum 262 bred out in Khandesh tract) because the latter possessed a higher ginning value. The defects in Jarila in this region were: (*a*) its susceptibility to damage by late and heavy rains in the eastern part of the tract; (*b*) its tendency to lodge; and (*c*) its improper boll opening. It could not, therefore, be considered as a permanent solution of the cotton problem of the tract. Hybrid 420, evolved in 1935 from the cross Bani (*indicum*) x Garo Hill cotton (*cernuum*), answered to the needs of the tract (Kolte, 1954). Like Jarila, Hybrid 420 showed high wilt resistance and ginning outturn (*c.* 34%). Besides, it also possessed a strong and stiff stem with very good boll opening habit. Its lint was very fine and silky and was adjudged suitable for spinning up to 31's warps. In spite of its slightly lower yielding capacity, H. 420 started gaining popularity after the Second World War, obviously due to its fibre qualities (Plate II-c).

Due to varying climatic and soil conditions prevailing in Vidarbha tract as a whole, it was difficult to fit a single *elite* strain in the region. Cotton breeding in the area was, therefore, regionalised, there being four centres; Nagpur, Akola, Yeotmal and Buldana. These regional schemes operated from 1948 to 1953 during which period promising strains, viz., No. 91 and Malini (M.5A) were evolved by reselection from H.414, a sister strain of H.420 and by selection from *malvense* cotton, respectively. No. 91 proved suitable for the eastern part of the whole tract comprising Nagpur and Wardha districts and the Ghat area of the Yeotmal district. Malini on the other hand proved suitable for the western part of the whole tract, viz., Buldana district. During recent years further progress has been made. Strains derived from the cross (H.420 x J.D.487) are very high yielders, possess 37 to 39 per cent. ginning value and can be spun to 36's warps. They are suited to the eastern part of the tract. In the west, the area is comparatively drier; B.12A, a selection from 907 has done well in this part. Its ginning value is 40 to 42 per cent. and it is capable of being spun to 32's. A reselection, strain No. 462 from H. 420, has very fine long staple (22.4 mm. halo length). All these strains were under major trials at the various centres by 1956 (Fig. 19 and Plates XX-a.b.c).

Khandesh Tract: Cotton improvement work in Khandesh tract has been reviewed by Khadilkar (1947a,b, 1950). Failure of all the efforts to acclimatise *hirsutum* cotton in the tract and unsatisfactory performance of even the other available types of *herbaceum* and *arboreum* cottons brought out the necessity of trying to improve the indigenous cottons by selection and hybridization. Selection of *bengalense* types from the local Jadi Mixture was started in 1921 at Dhulia and N. Roseum 6, a type superior in ginning outturn (40% *vs.* 35%) was evolved and released for cultivation in 1926. Several cultures obtained from the cross Bani (*indicum*) x Comilla (*cernuum*) made as early as 1908 were being maintained. Single plant selections and progeny

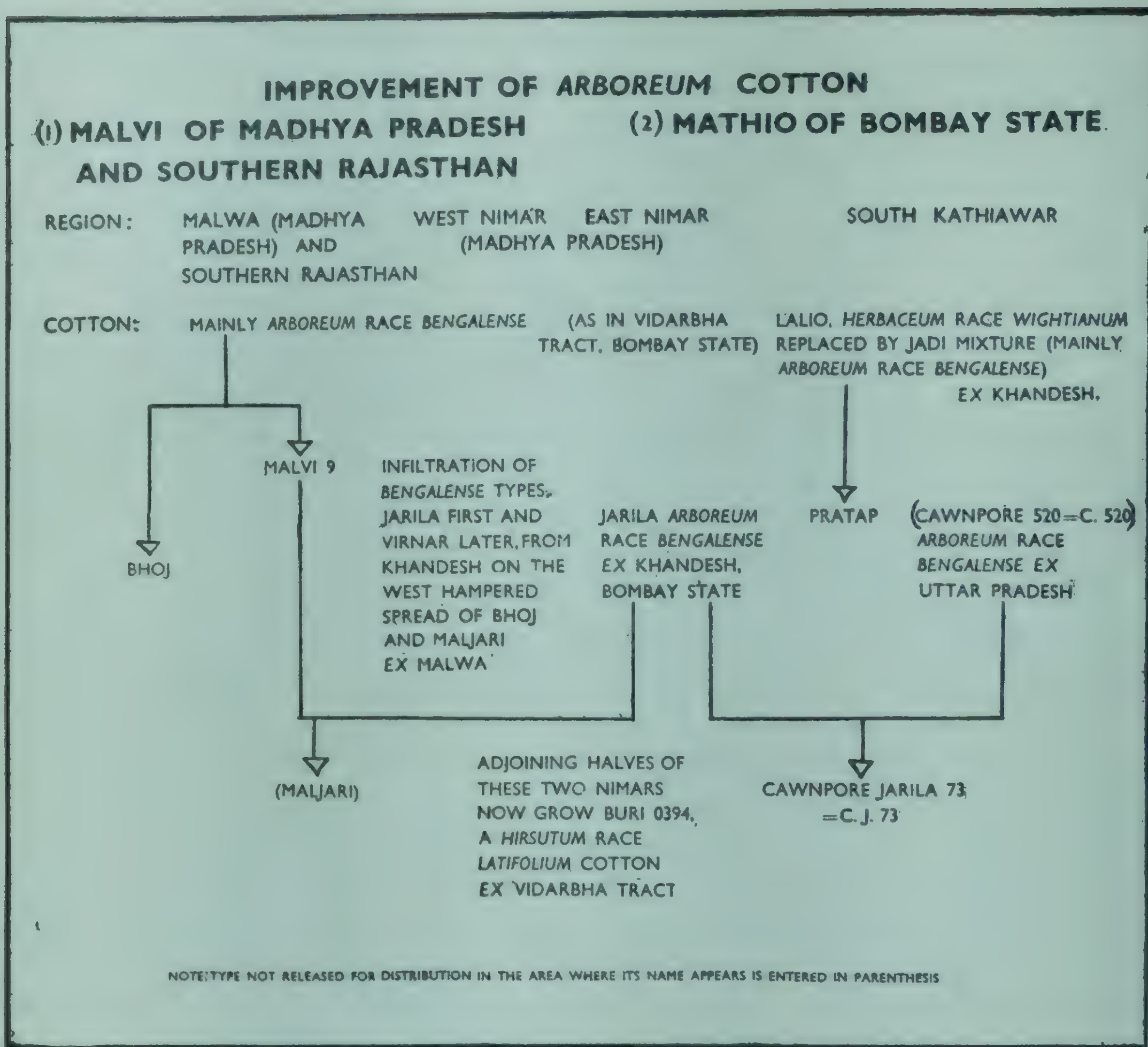


Fig. 20. Improvement of *arboreum* Cotton

tests were made in these cultures during 1926-32 and a type Banilla with 0·7" staple was evolved. It remained popular for a short period of about six years, since in fields contaminated with *Fusarium* wilt this variety was severely affected. Breeding of a wilt-resistant type was, therefore, very necessary. Since, however, fields at Dhulia were free from the fungal organism, breeding station had to be shifted to Jalgaon located in the deep black cotton soil tract heavily infested with the wilt organism, *Fusarium vasinfectum* Atk. At Jalgaon single plant selections for wilt resistance in particular were made in *bengalense* cotton, Verum 262, received from the Vidarbha tract. The experimental plots were highly infected with wilt, artificially. A *verum* cotton, named Jarila, was thus evolved. It proved highly wilt-resistant under field conditions and possessed longer (0·85")and finer staple. In 1943 it was declared a standard trade variety replacing the old Broach standard. Because of its merits it infiltrated into Vidarbha tract in the west, Aurangabad district of Gaorani tract in the south and Malwa and Nimar tract in the north. Its ginning percentage was only *c.* 35 per cent. To improve this character it was crossed in 1937 with N. Roseum 5, a type possessing 44 per cent. ginning value. Simultaneous improvement in staple length, yield, suitability to lighter soils, immunity to wilt and tolerance to continuous wet weather was contemplated. A culture, later named Virnar, was isolated. In its trials during 1943-47 it yielded 15 per cent. more seed cotton than Jarila and possessed ginning percentage as high as *c.* 39. Even in light soils it performed better than Jarila with the result that it has displaced the latter over most of the area in Khandesh tract (Plates II-b. and XXI-a).

Malvi Tract (Madhya Pradesh). Malvi tract comprises the Malwa and Nimar regions of Madhya Pradesh and southern part of Rajasthan. The Nimar tract grew to a limited extent in the 19th century fine cottons such as M'hahlie (*G. herbaceum*) and Bani (*G. arboreum* race *indicum*) which were used by the famous spinning industries at Chanderi, Maheshwar, Sironj and Nimar (Gadkari and Simlote, 1949). The main cotton in the whole tract was originally *arboreum* race *bengalense*. *Gossypium hirsutum* race *latifolium* types, Georgian Upland introduced into the area in 1842 and Cambodia first received in Malwa in 1912, got incorporated in the local *bengalense* cotton as a mixture. The cotton of the region is also known by the name of Malvi.

Work on the improvement of cotton in this region was initiated at Indore in 1924 and has been reviewed by Simlote (1956), Kocharekar (1955), Gadkari (1954), Simlote and Kocharekar (1954), and Gadkari and Simlote (1949). Single plant selections made from the local bulk led to the isolation of several *bengalense* types from among which Malvi 9 proved to be the best in yield, ginning and lint qualities. This type was released for general cultivation from 1935 onwards. High susceptibility to wilt attack was detected in Malvi 9 during multiplication of its seed. Reselection in Malvi 9 for wilt resistance was not successful. Selection from

local bulk obtained from Dhar led to the isolation of another *bengalense* type, Bhoj, which besides being wilt-resistant was equal to Malvi 9 in other respects. It was, therefore, released for general cultivation in 1942. Its spread was hampered owing to infiltration of Jarlia from Khandesh in the south. Jarila was preferred by the traders for its superior ginning and spinning qualities and, therefore, it was cultivated by the farmers although it showed inferiority to Bhoj in productivity. With a view to combining yielding ability of Bhoj or Malvi 9 with the other properties of Jarila, hybrid progenies obtained by intercrossing them were studied critically at Dhamnod before 1948 and at Khargone later. Maljari evolved from the cross (Malvi 9 x Jarila) has proved better than the Khandesh types Virnar and Jarila. Since 1954 efforts are under way to distribute Maljari particularly in Nimar tract where Jarila predominated for a period and was later succeeded by Virnar. Hybrid generations of Malvi 9 and Bhoj with newer, high ginning, quality strains such as 91, 111 and Malini from Vidarbha tract, Gaoranis from Gaorani tract and Pratap from Mathio tract are also under study (Fig. 20 and Plate XXI-b).

Mathio Tract (Bombay State). Khandesh Jadi Mixture also found its way into South Kathiawar at the turn of the century. It displaced local Lalio (*herbaceum*) cotton because of its hardiness and early maturing habit which enabled it to resist and evade damage due to frost. It acquired the name Mathio because its leaves resembled those of *moth*, *Phaseolus aconitifolius*. In place of Lalio, Mathio became constituent of cotton recognised as Dholleras by the traders. The trade name Dholleras is derived from the port of Kathiawar of that name through which the cotton was shipped. The other component of Dholleras is *herbaceum* cotton, Wagad.

Mathio cotton is well suited to the sandy loam (*gorat*) soils of the region. Scheme for improvement of this cotton was put into operation at Amreli in 1937. It was intended to try early strains of Wagad (*herbaceum*) for replacing the inferior Mathio cotton predominantly *arboreum* in composition. Some of the improved *arboreum* strains also tried out were, N. Roseum, Jarila, Banilla, Verum types and Cawnpore 520. The last mentioned type was the best immediate substitute for the tract and was distributed as such in 1942. In the meanwhile selection work on local material was in progress and by 1945 one of the selections named Pratap was released for general cultivation as it showed the maximum improvement over the local in ginning outturn, fibre length and spinning value (Patel and Patel, 1948). Crosses of Cawnpore 520 with Jarila and Pratap and of Pratap with Madras *arboreum* (Karunganni) types were also under study. C. J. 73, isolated from the cross, Cawnpore 520 x Jarila, has been found to be superior to Pratap (Phadnis, 1957) (Plates III-a.b and XXII-a).

Gaorani Tract (Bombay, Mysore and Andhra Pradesh States). Gaorani cotton, also known by additional names such as Umri Bani and Bani is reputed for its quality, especially the strength and silkiness of the

fibres. Even prior to purification, its principal component was *G. arboreum* race *indicum* (Sawhney, 1938). Like Bani (*indicum*) cotton of Vidarbha tract it showed three main defects, viz., low yield, low ginning and poor boll opening. Work on amelioration of this cotton is in progress since 1929 and the results obtained have been recorded by Khurshid (1947), Bederker (1955a, b; 1956) and Joshi (1956b).

Selection technique has been used with remarkable success in the improvement work done on Gaorani cottons at Parbhani (1929), Nanded (1941) and Badnapur (1952) in Bombay State. Prior to 1949, efforts to breed higher ginning and higher yielding types led to the production of two types, Gaorani 6 and Gaorani 12 suited to different regions in the tract. Gaorani 6 was released in 1936 for distribution in Nanded district and the adjoining half of Parbhani district of Bombay State and in Nirmal *tehsil* of Adilabad district of Andhra Pradesh. Gaorani 12 proved to be especially suited to *chalka* soils and was released in 1950 for general distribution in the western half of Parbhani district, Osmanabad district and parts of Aurangabad and Bhir districts of Bombay State and in Bidar and Gulbarga districts of Mysore State (Plate XXII-b).

Reselection exercised for improved agronomic characters in Gaorani 6 and Gaorani 12 cottons at Nanded gave evidence of the existence of considerable amount of residual heritable variability in them (Bederker, 1955b). Types were evolved superior in yield, staple length, ginning percentage, boll size and resistance to wilt or lodging (Bederker, 1955a, b). An isolate, 1494, has been recommended as a better substitute for Gaorani 6 in Nanded district in particular, the district known for the superior quality of its cotton. This variety, 1494, has better plant habit and is more productive besides possessing longer staple, greater spinnability, bigger bolls and wilt resistance. Strain 1422 isolated from Gaorani 12 has been released as a substitute for the parental variety since it is more productive and possesses a higher ginning value. It is also wilt-resistant. It gave encouraging results even in the districts of Aurangabad and Bhir where Jarila is popular (Joshi, 1956b). Another high ginning type, 1585, has been recommended for the less retentive soils of Adilabad district (Andhra Pradesh) where a high ginning coarse cotton was being grown prior to distribution of the comparatively low ginning finer cotton, Gaorani 6. Strain 1946 is a type that combines fibre quality of 1494 and high ginning of 1585 and 1422. It is also one of the types recently released for general cultivation in the Gaorani tract (Bederker, 1956). Lately still more superior Gaorani varieties have been evolved by continued selection alone and some hybridization work has also been undertaken (Bederker, 1956) (Plate II-a and XXIII-a.b).

Gaorani 12 became unpopular in the western part of Parbhani district by 1954 because of its inferior ginning and yield values as compared to the local Jadi Mixture or Jarila cottons. A type isolated earlier in 1945 from

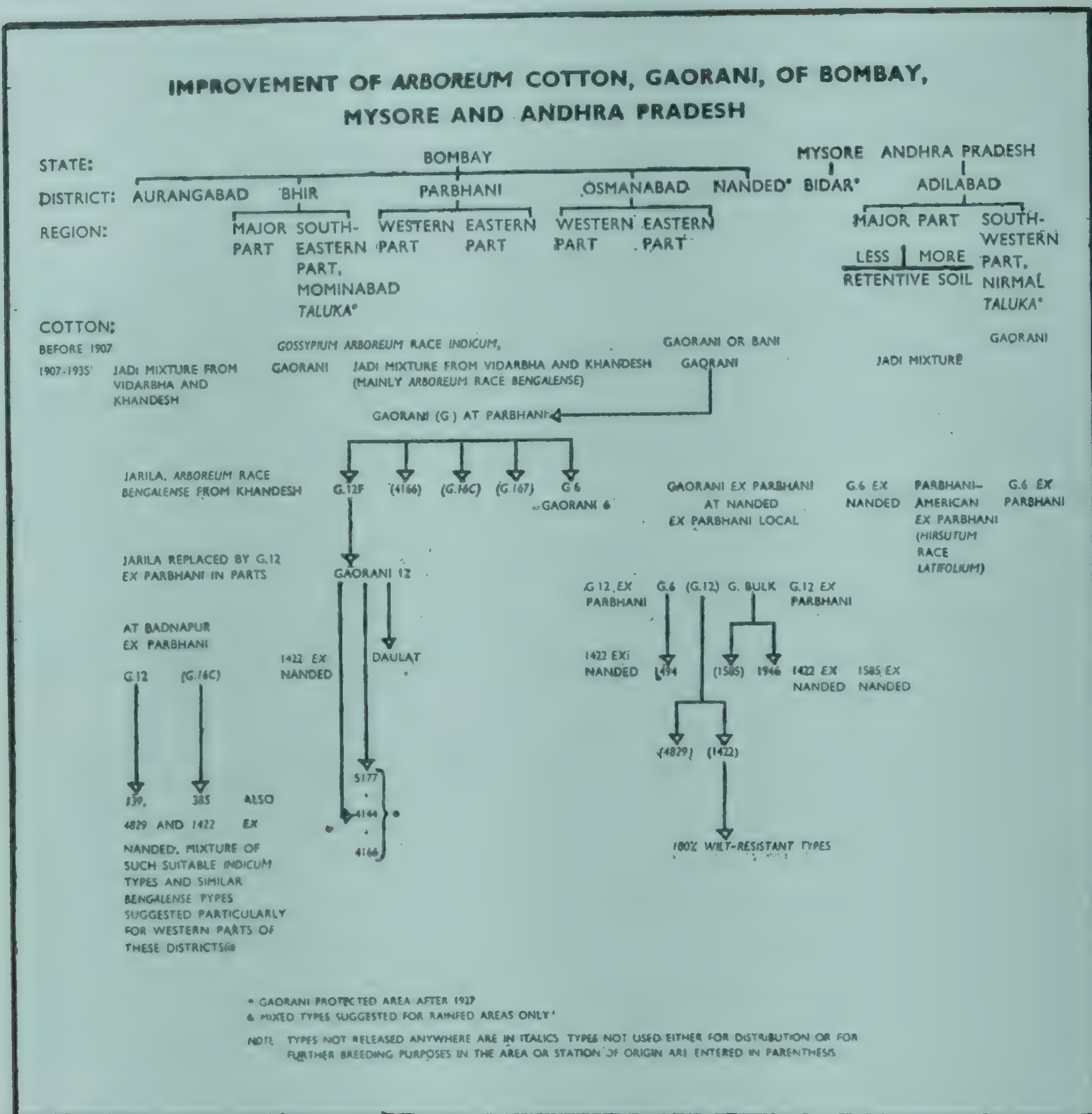


Fig. 21. Improvement of *arboreum* Cotton, Gaorani, of Bombay, Mysore and Andhra Pradesh

Gaorani 12 by reselection at Parbhani appeared more prolific. It was named Daulat and released as a substitute for Gaorani 12 in this particular area in 1955 (Joshi, 1956b). The performance of Daulat during years of abnormal monsoons is unsatisfactory as compared to that of the local. Its yield suffers if monsoon rains are either too excessive or too meagre and also if September rains are too little or too much. Local bulk does not suffer so much from such vagaries of the monsoons. Its plasticity may be due to its unselected heterogeneous nature. Taking into consideration this very important factor of vagaries of the monsoons in this zone, Joshi (1956b) has suggested that mixture of selected strains such as 5177, 4166 and 4144 superior to Daulat may probably be released for general cultivation here as a bulk population of different genotypes (Fig. 21).

Gaorani 12 was distributed for cultivation in Aurangabad and Bhir districts, in place of local Jadi Mixture or Jarila cottons. Here too Gaorani 12 fared badly. Moisture conditions here are very hazardous, average rainfall being about 25 inches and that too irregular. The western portions of the districts are particularly often affected by droughty conditions. Earlier efforts to introduce *indicum* cottons, Gaorani in 1916 and Banilla in 1929, had similarly failed. Even Virnar, a *bengalense* type from Khandesh and Daulat, an improved *indicum* cotton, proved unsuitable here (Joshi, 1956b). According to Joshi (1956b), a combination of superior selected strains of *indicum* and *bengalense* origin provide the only and immediate solution to the problem of improving cotton crop of this area. In Purna, Dudhna and Bendsura irrigation project areas of Parbhani, Aurangabad and Bhir districts, respectively, however, quality Gaorani strains can be tried out under irrigation.

BENGALS

Cottons of the Punjab, western Uttar Pradesh and northern Rajasthan predominantly or wholly belonging to *arboreum* race *bengalense*, are recognised by the trade name of Bengals. These cottons are grown as summer crops mostly under rainfed conditions. Sowing period varies from April to July and pickings extend from September to January. In Rajasthan, Bengals are grown on the coarse (desert) alluvium whereas in Uttar Pradesh and the Punjab they are grown on the riverine alluvium and also on the soils of the sub-montane region of the Himalayas. In Bundelkhand tract of Uttar Pradesh (Banda, Jhansi, Jalaun and Hamirpur districts), this cotton is grown on black or red soils.

Punjab. The Punjab grows *arboreum* race *bengalense* cottons from time immemorial. The red-leaved (*sanguineum*) *arboreum* of the part of the Punjab now included in western Pakistan, was locally known as Multani cotton. It resembles race *indicum* in certain anatomical features and was, therefore, considered by Ramanathan (1938) as a probable relic form of *indicum* grown in the region prior to invasion by *bengalense*. Silow (1944a), however, groups

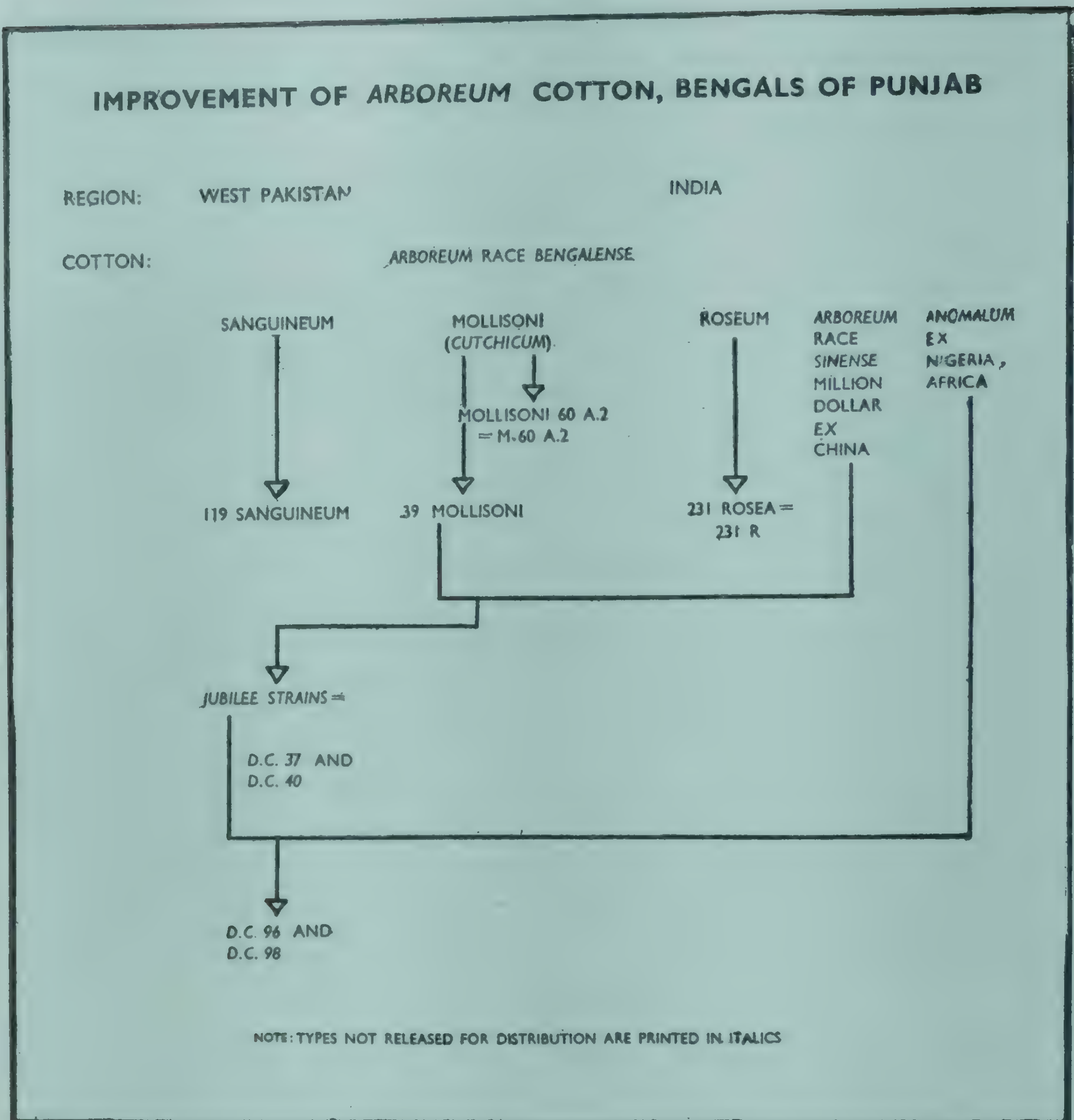


Fig. 22. Improvement of *arboreum* Cotton, Bengals, of Punjab

sanguineum under race *bengalense*. Mollisoni, the predominant *arboreum* of the Punjab also belongs to race *bengalense* (Hutchinson, 1938b; Silow, 1944a). Mollisoni cotton is broad-leaved and white-flowered like the genetic type *cutchicum* of race *bengalense*. Another genetic type of *bengalense*, viz., the white-flowered and narrow-leaved *roseum* is also cultivated in the Punjab. The *hirsutum* cottons were introduced into the State in 1850 after which they crept into the local cotton as a mixture. The component species in the mixed cotton were subsequently isolated and the improved types of *hirsutum* were grown in the part of the Punjab which went to Pakistan in 1947. Improved *arboreum* race *bengalense* types nearly occupied the whole of the eastern portion of the Punjab which remained with India. Since then, however, a large portion of this region is given over to new long staple types of *hirsutum* cottons ; *bengalense* having receded to the sub-montane region of the Himalayas.

Isolation and improvement of *arboreum* cotton in the Punjab began with the establishment of the provincial Department of Agriculture in 1905. Prior to 1925, high yielding selections from Mollisoni cottons, viz., Z. Mollisoni, 278 Mollisoni and Mollisoni 60-A·2 were evolved at Lyallpur (now in Pakistan). After 1925, more productive Mollisoni and *sanguineum* selections, such as 15 Mollisoni, 39 Mollisoni and 119 Sanguineum, were isolated.

The type Mollisoni 60-A·2 was the type prevalent in the south-eastern part of the Punjab retained in India after 1947. Work on the improvement of this cotton was begun at Hansi earlier in 1941, because by that time the type had deteriorated due to contamination with two to three per cent. of yellow-flowered plants. Mass selection against yellow-flowered types in the contaminated Mollisoni 60-A·2 cotton led to the isolation of a better ginning and higher yielding type. Simultaneously, work on single plant selection in field bulk of cotton was in progress and two new varieties, 231 Rosea (231 R) and 258 Mollisoni were evolved. None of these types could be spun to more than 8's warp. The distribution of the highly productive strain 231 R was withheld because preference had to be given to the spread of better spinning *hirsutum* cottons in the post-Independence period. In the sub-montane region, however, 231 R was released for distribution as the region was unsuited for *hirsutum* cultivation (Anon., 1956a) (Plate XXIV).

Hybridisation experiments also were begun in 1930 at Lyallpur with the object of improving the lint quality in the Punjab *arboreums*. The type 39 Mollisoni was crossed with another *arboreum* cotton, Million Dollar, from China and a number of strains collectively designated as Jubilee strains were evolved. D. C. 37 and D. C. 40 from among them appeared most promising as regards giving higher cash returns (Afzal, 1946a, 1948). Still greater improvement in the length, fineness and strength of the staple was obtained by crossing Jubilee with one of the wild species, *G. anomalum*. D. C. 96 was reported to be a promising strain evolved from this interspecific cross ; it could be spun to 23's warps (Afzal, Sikka and Rahman, 1945). At Hansi recently another

sister strain, D. C. 98, has been reported to be superior to Mollisoni 60-A·2 in mean fibre length, ginning percentage and lea strength at 14's (Anon., 1956b) (Fig. 22).

Western Uttar Pradesh. Early work on the improvement of cotton in Uttar Pradesh has been summarised by Sethi (1947), Ansari (1949) and Simlote (1956).

A fine linted strain, Jalaun 1, was extracted from the indigenous cotton of Jalaun district by Burt about the year 1920. It was released for Bundelkhand tract comprising the districts of Banda, Jhansi, Jalaun and Hamirpur. After the lapse of a few years it lost its purity by getting mixed up with the inferior local cotton.

In Aligarh district of the State, improvement, at first, was not sought in the quality of cotton but only in its yield and ginning. In 1917, a *roseum* type, Aligarh 19 (A.19) fulfilling these requirements, was isolated by Parr from the local cotton. It had short and coarse staple but owing to its high productivity it spread to such an extent that it ousted or contaminated pockets of land that grew finer quality cottons known to the trade as Kashipur, Chandausi and Harpalpur styles. For this reason, the cultivation of A.19 was soon considered undesirable.

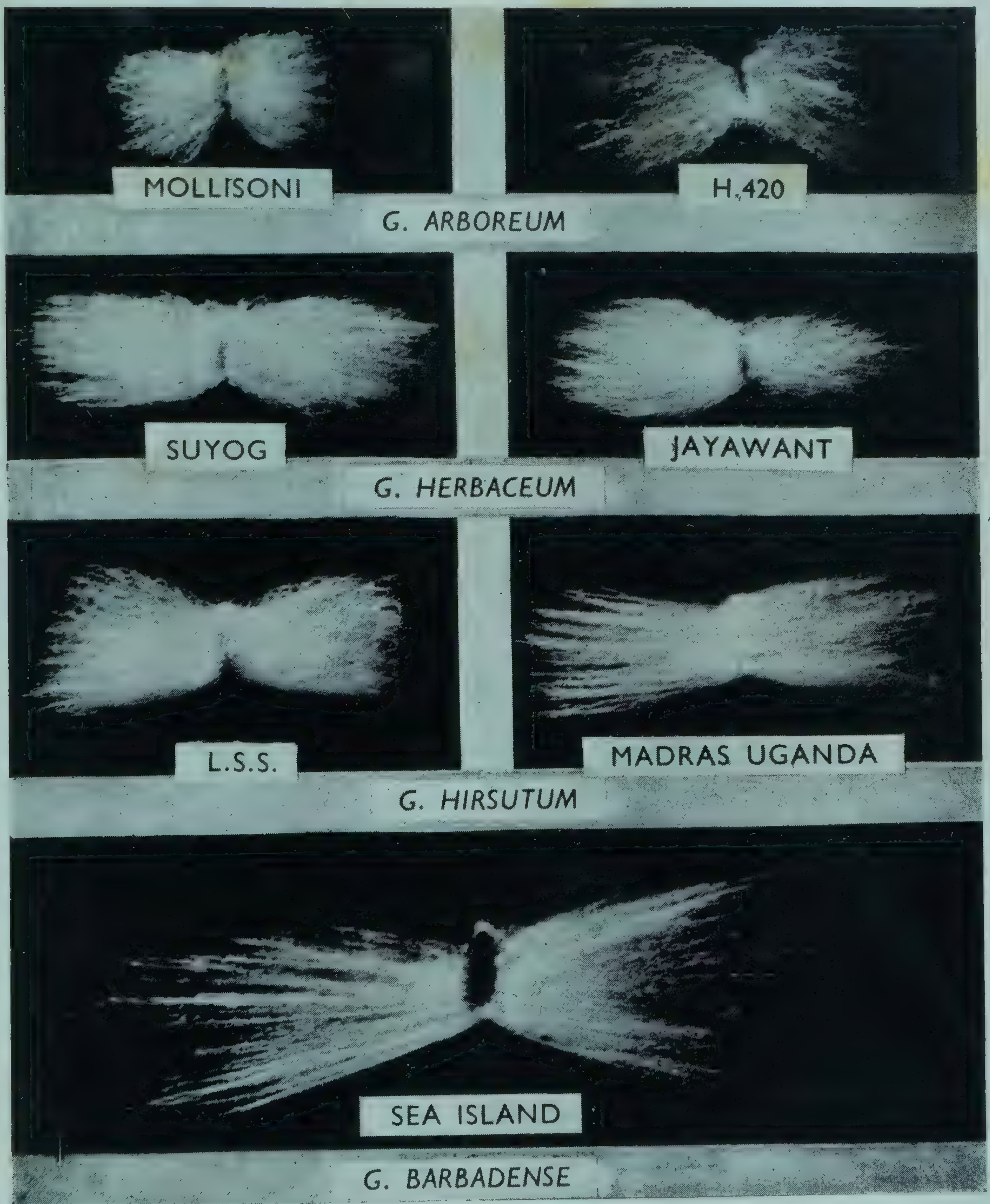
Hybridisation experiments begun by Leake in 1908 led to the isolation of an improved type Cawnpore 402 (C.402). It was obtained by first intercrossing the two *bengalense* types, *roseum* and *sanguineum* and the F_1 so obtained was later crossed with the race *cernuum* in order to improve the ginning value. Cawnpore 402 could be spun to 18's.

Several single plant selections were made in 1920 in Rohilkhand area comprising the districts of Dehra Dun, Saharanpur, Muzaffarpur, Bijnor, Moradabad, Nainital, Rampur, Bareilly and Badaun. From among these selections Cawnpore 520 (C.520) proved to be the most promising in trials conducted in the subsequent years. It registered an all round improvement over the local bulk in yield, ginning (35 per cent. *vs*. 30 per cent. approx.), staple (0·76″ *vs*. 0·70″) and spinning (12's *vs*. 10's H.S.W.C.) (Simlote, 1956).

During the period 1933-37, 27,000 single plants were selected from all over the cotton area of the State and tried out at four stations, Kanpur, Raya, Nagina and Belatal. From among them all, 35/1 came into prominence due to its consistent high yield and spinning value as compared to C.520. (Plates II-d and XXV-a).

Further improvement of *arboreum* cottons of Uttar Pradesh, is being sought to be made through their hybridization with superior quality *arboreums* such as Gaoranis and Virnar from the Deccan India, Shan from Burma and Million Dollar from China (Ansari, 1949 ; Anon., 1956b).

Northern Rajasthan. Prior to the opening of the Gang canal in 1929, no cotton was grown in this region. Experiments were conducted during the

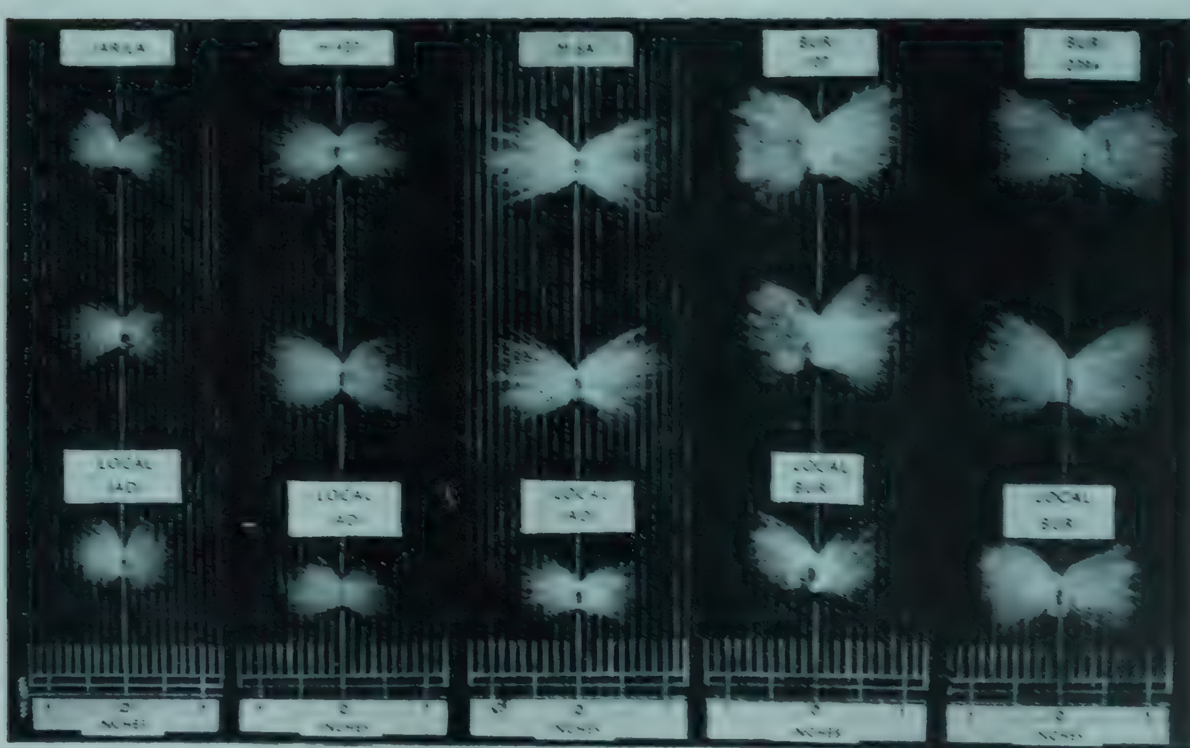


Variation in the Staple Length of Different Species of *Gossypium*

PLATE XX

a. M 5A

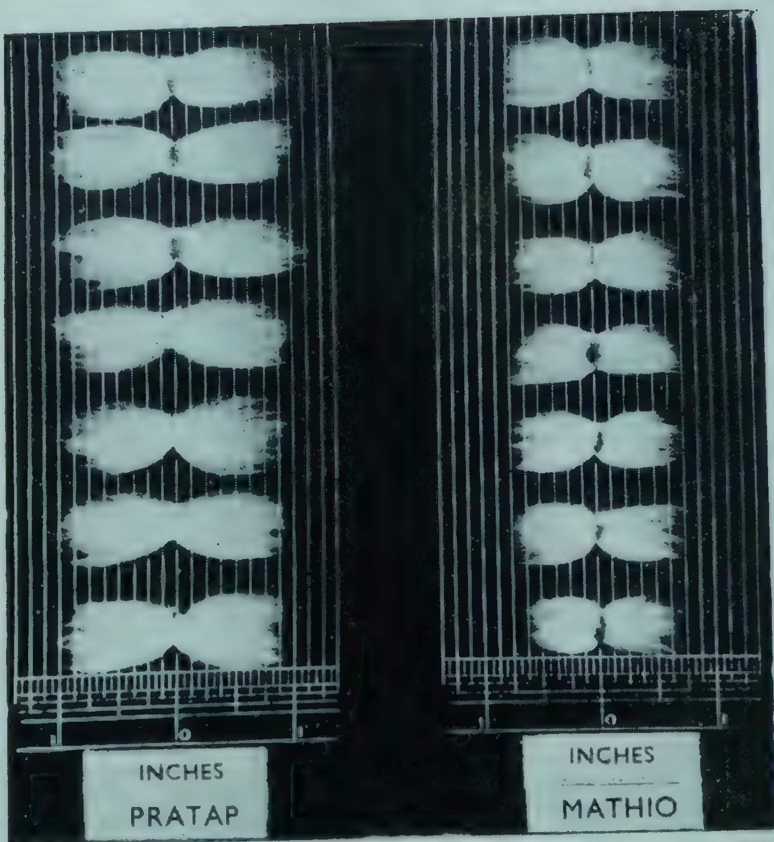
b. No. 91



c. Staple Length of Cottons from Vidarbha

a. Staple Length of Khandesh Cottons

b. Staple Length of Madhya Pradesh Cottons



a. Staple Length of Mathio and Pratap Cottons

b. Staple Length of Gaorani Cottons

period 1931 to 1941 at Ganganagar, to determine the cotton type best suited for the area. The first settlers in the newly opened Gang canal colony were mostly from the Punjab. They brought with them the Punjab *hirsutums* and Mollisoni *arboreums*. Experiments showed that the yield of *hirsutum* cottons was distinctly lower than that of some improved *arboreum* types from Uttar Pradesh. Hutchinson and Panse (1936), therefore, recommended the cultivation of C.520 from Uttar Pradesh. Another *bengalense* selection, Rohilkhand 18 from the same State, proved superior to C.520 in this region in every respect ; especially in ginning (40 per cent. *vs.* 35 per cent.) (Simlote, 1956). Rohilkhand 18, renamed Ganganagar 1, was recommended to the cultivators in 1942, but owing to the country-wide drive in the post-Independence period to substitute, wherever possible, the long staple *hirsutums* in place of the shorter staple types, this type could not make any headway (Fig. 23).

SOUTHERNS

Southerns is a general trade name given to *herbaceum* cottons, Kumpta, Westerns, White Northerns and Uppam ; annual *arboreum* cottons, Mungari, Red Northerns, Cocanadas, Karungannies and Chinnapathi; and the perennial cottons, Salems, comprising Nadam (*arboreum*) and Bourbon (*hirsutum* race *punctatum*) grown in the Deccan. Only the annual *arboreums* will be considered first. Of these Mungari is a summer sown crop grown in red loam of especially the western part of Rayalaseema tract in Andhra Pradesh and the adjoining areas of Mysore State. It is sown in June-July and picked by January-February. It forms a trade component of Westerns, grown in the same region as a winter cotton. Karungannies are winter *arboreums* grown on the black soils of Madras State; sown during October-November and harvested during March to June. Red Northerns are grown on red loams of eastern Rayalaseema tract in Andhra Pradesh and are considered as a trade component of the Cocanadas grown in the same State. On the black soils of the eastern Rayalaseema tract of the State an improved white-linted *arboreum*, Nandyal 14 (N.14) has substituted, to a certain extent, the White Northerns grown earlier in the area. Both Red Northerns and N.14 are picked during February to April but the sowings are made either in June-July season or August to October season. Cocanadas are grown on a wide range of soils varying from poor shallow gravelly red loam to rich deep black clay. The sowing season extends from July to September depending on whether the soil is red, intermediate or black but the harvests usually take place during January to April, irrespective of the sowing time. Chinnapathi is grown in Orissa and the adjoining part of Andhra Pradesh. On dry lands it is planted in May-June and harvested completely by November in most of the area. On wet lands of Visakhapatnam district (Andhra Pradesh), however, it is sown in December-January and picked by July-August; this

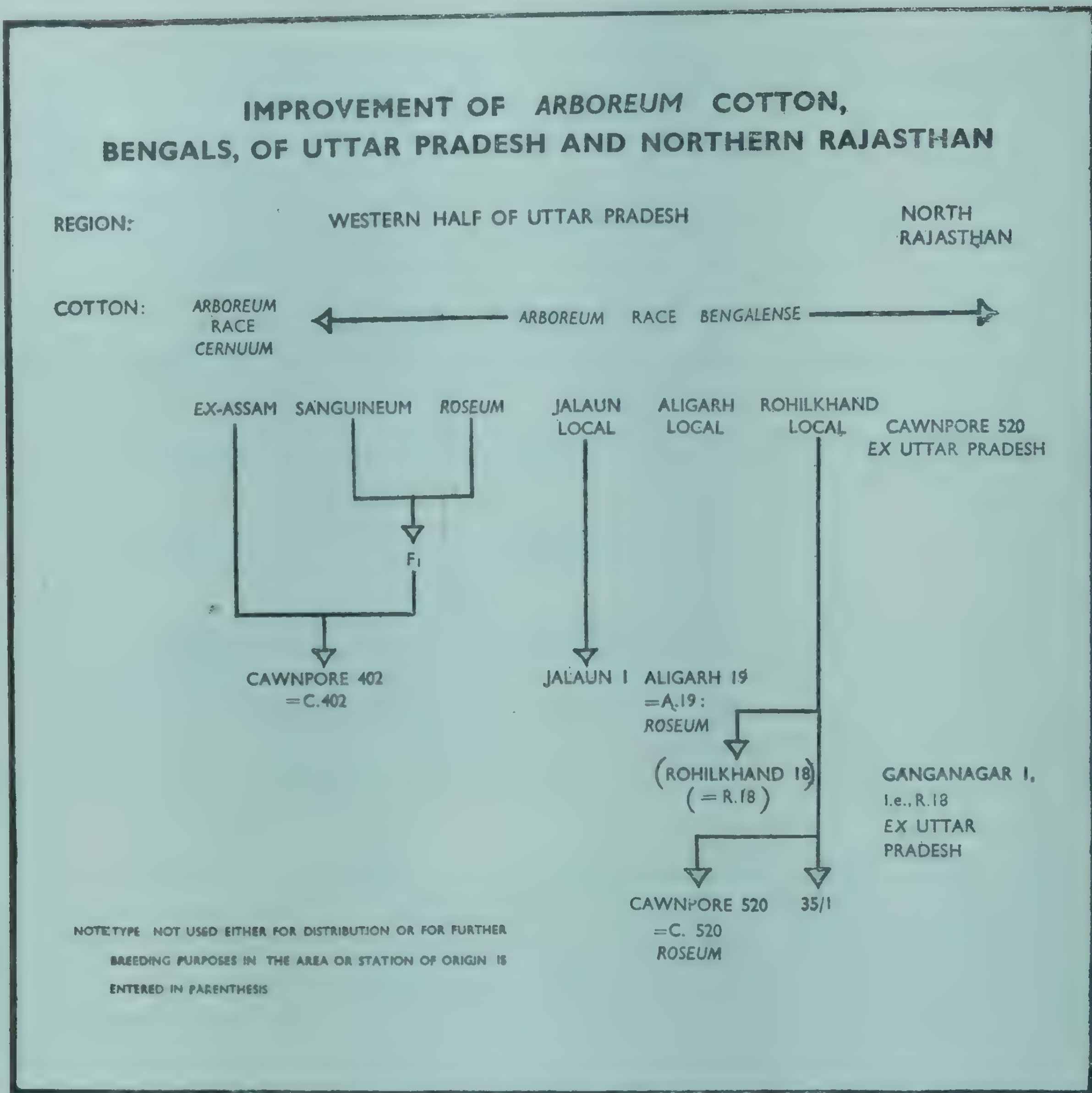


Fig. 23. Improvement of *arboreum* Cotton, Bengals, of Uttar Pradesh and Northern Rajasthan

cotton is recognized by the name Buradapathi. All these *arboreums* are grown as rainfed crops; only a very limited area of Karungannies is also grown under irrigation.

Karungannies (Madras State). The original Karunganni cotton belonged to the race *indicum*. A variable mixture of this cotton with Uppam (*herbaceum*) and types derived from hybridization between them are known by the name of Tinnies or Tinnevellies. Both Uppam and Tinnies have now been largely replaced by *indicum* derivatives (Anon., 1954; Kalyanaraman, 1955).

Karunganni cotton was selected as initial breeding material in preference to Uppam because the former was superior in quality and showed greater genetic variability. It was intended to evolve a type which would eventually unify the region under one cosmopolitan *arboreum* race *indicum* strain. Breeding work was carried out at Koilpatti and Coimbatore. Mass selection of heavy bearing plants led to the evolution of two types Company No. 2 and 3 in 1915. They showed improvement in ginning outturn and staple length but yielded seed cotton lesser than the local mixture as a result of which they soon fell out of cultivation. Pure line selection in Karunganni cotton led to the isolation of two types A.10 and C.7; the former superior in ginning and more suitable for the central districts and the northern half of the southern districts of the State, and the latter superior in quality and better suited to the sourthern half of the southern districts. These two selections enjoyed popularity for little over a decade from the time of their release about the year 1921. An early and drought-resistant type, Karunganni 1 (K.1), obtained from C.7 by reselection also proved superior to the local in productivity and ginning outturn. Its cultivation spread to Coimbatore district and all the southern districts of Madras State.

None of the types evolved thus far displaced the inferior quality Uppam which continued to be popular in the south-eastern coastal region because of its property of withstanding heavy bud and boll shedding caused by the February rains. Simultaneously with the development of K.1, pure line selection was in progress under the "Madras *herbaceum* Scheme" at Coimbatore in the hybrid material obtained by inter-crossing the races *indicum* (Northerns and Cocanadas) and *cernuum*. As a result of this work, Karunganni 2 (K.2) having triple ancestry, Northerns, Cocanadas and *cernuum* and Karunganni 5 (K.5) having a double ancestry, Northerns and *cernuum* were evolved for the southern (Uppam area) and central districts, respectively (Kalyanaraman, 1955; Iyengar and Santhanam, 1956). In regions other than their own these two types were misfits; pure line selection in similar hybrid material was, therefore, continued. A type, 6186-9, has been obtained which promises to be a universal one for the whole of the *arboreum* area of Madras State (Santhanam, 1958b) (Fig. 24 and Plates I-a and XXV-b).

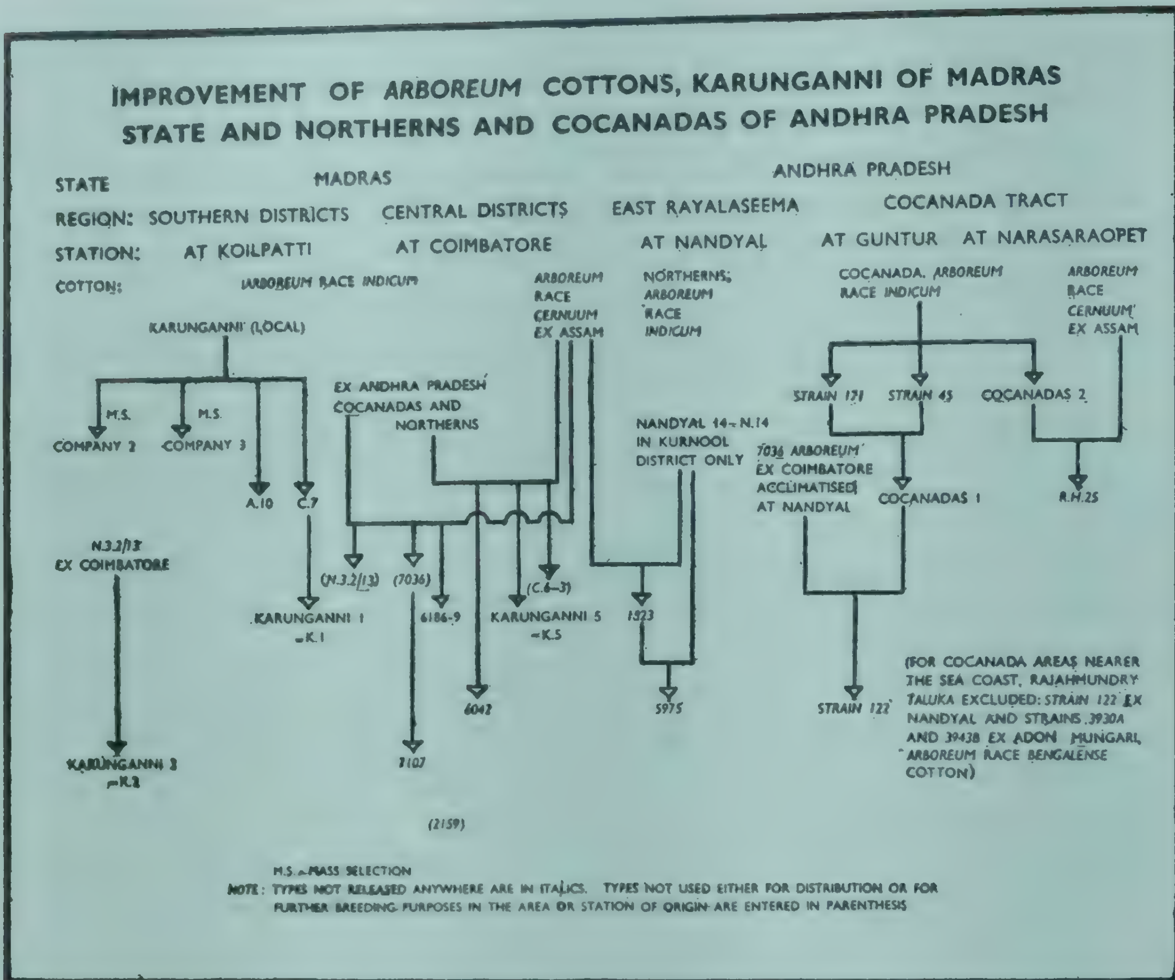


Fig. 24. Improvement of *arboreum* Cottons, Karunganni, Northerns and Cocanadas

In recent years most of the central Madras State area has been given over to the cultivation of Cambodia (*hirsutum*) cottons.

Northerns (Andhra Pradesh). Northerns were initially a mixture of *herbaceum* race *wightianum*, *arboreum* races *indicum* and *bengalense*, and *hirsutum* race *latifolium*. The major components were *herbaceum* and a genetically red lint type of *arboreum* race *indicum*; White Northerns contained 50 per cent. or more plants of the former species and Red Northerns largely comprised the red lint type of the latter species. Bulk samples of Northerns were collected at Nandyal from Bellary district (Mysore State) and Rayalaseema district (Andhra Pradesh) in 1906. On scrutiny it was found that the *herbaceum* component consisted of several plants with short and coarse lint whereas the *indicum* component possessed plants with fairly fine and strong lint of a staple length ranging from $\frac{3}{4}''$ to 1". In the selection programme *herbaceums* and the red-linted types of *indicum* were avoided. An *arboreum* race *indicum* type superior in staple and quality of lint was thus isolated and named as Nandyal 14 (N.14). It was released for distribution in the Northerns tract in 1918, but owing to its low productivity and poor ginning (25 per cent. only) it could not cover the entire area. Its cultivation is restricted to Kurnool district of Rayalaseema tract (Andhra Pradesh) but it is reputed to be the best quality *arboreum* cotton (Venkoba Rao, Seshadri Ayyangar and Jagannatha Rao, 1955a) (Plate XXVI-a).

With a view to improving the ginning value of N.14, its hybridisation with other *arboreums* reputed to be good ginners was begun in 1938 (Venkoba Rao, Seshadri Ayyangar and Jagannatha Rao, 1955a). Strains ginning up to 34 per cent. and spinning up to 39's have been reported from *cernuum*-N.14 hybrids ; the strain 5975 is one of them.

In yield trials conducted at Nandyal, a red lint *indicum* type, Cocanadas 1 and some white lint strains of triple ancestry (Northerns, Cocanadas and *cernuum*) obtained from Madras State proved significantly more productive than N.14. By crossing Cocanadas 1 with 7036, one of the aforementioned strains of triple hybrid origin, strain 122 has been evolved which shows about six per cent. more ginning and yields about 10 per cent. more lint of finer quality and greater strength than N.14 (Venkoba Rao, Seshadri Ayyangar and Jagannatha Rao, 1955a ; Seshadri Ayyangar, Nageswara Rao and Rama Rao, 1956). It has not yet been released for distribution.

Cocanadas (Andhra Pradesh). Cocanadas derive their name from the port of Cocanada (now spelt as Kakinada), from which these cottons were once exported. Red lint *indicum* as well as white lint *bengalense arboreums* together constituted these cottons ; the red lint type predominated. At one time, this red lint cotton was very much in demand because it could be dyed better. Now-a-days the situation has changed. Methods of dyeing all kind of cotton are now known. It is, therefore, proposed to replace it with

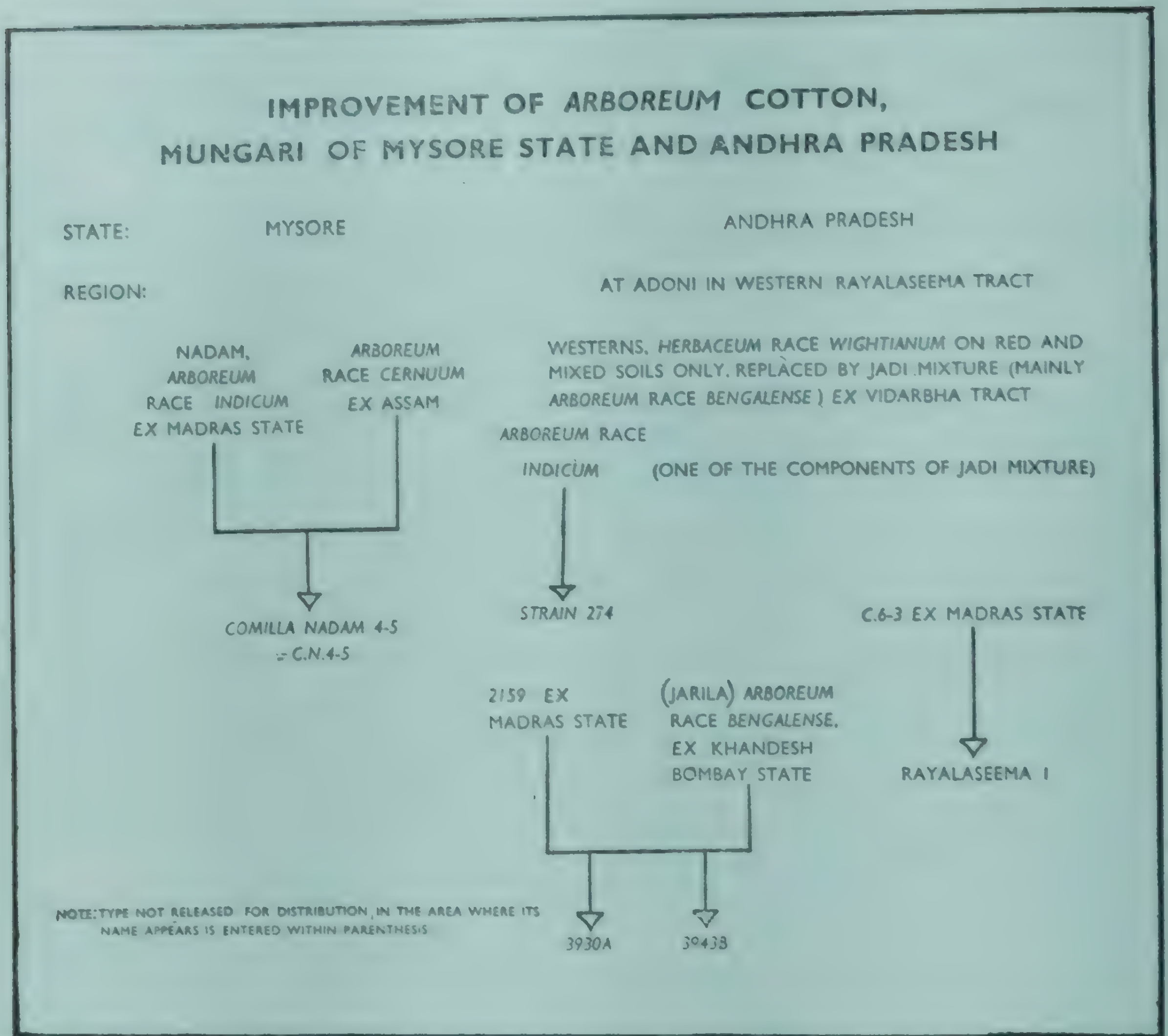


Fig. 25. Improvement of *arboreum* Cotton, Mungari, of Mysore State and Andhra Pradesh

better quality white lint types especially in the coastal region where red colour in the lint of Cocanadas does not develop well. In the mixed cropping system also it is proposed to use white lint types in place of Cocanada types which prove inferior in productivity and later in maturity when grown in this manner (Seshadri Ayyangar and Jagannatha Rao, 1955; Seshadri Ayyangar, Venkoba Rao and Venkata Reddy, 1956a).

Breeding work on Cocanadas was carried out at Guntur prior to 1940 and is in progress thereafter at Narasaraopet and Gurazala. Strain 171, isolated at Guntur by selection, yielded more cotton than the local mixture. On crossing it with another strain, strain 45, several promising derivatives were obtained out of which one, Cocanadas 1, was the best yielder. Cocanadas 1 was lighter in lint colour as compared to the deep coloured local cotton.

It was next intended to effect a conjoint improvement in depth of lint colour and length of staple of Cocanadas. The variety Cocanadas 2 possessing deeper lint colour and better fibre qualities was produced by 1948 by selection from local bulk. It could further be improved in yielding capacity by reselection or in yarn strength by hybridisation with *cernuum* as in the isolate, R.H.25 (Jagannatha Rao, Marar and Santhanam, 1953).

The red cottons do not enjoy the same popularity that they did earlier and are undesirable for use in mixed cropping system followed in the coastal region of Cocanadas tract (Seshadri Ayyangar and Jagannatha Rao, 1955). Seshadri Ayyangar, Nageswara Rao and Rama Rao (1956) have suggested the possibility of white lint strains possessing Cocanadas heritage, like the strain 122 evolved at Nandyal for the Northerns tract, proving suitable substitutes for Cocanadas in some of the areas. At Adoni (Andhra Pradesh) in the Mungari tract, two early maturing white-linted types, 3930A and 3943B, have been isolated from the cross of Jarila (*arboreum* race *bengalense* type evolved in Khandesh tract, Bombay State) with the strain 2159 of triple ancestry (Northerns, Cocanadas and *cernuum*) isolated at Coimbatore (Satyanarayana Murthy, Venkoba Rao and Jagannatha Rao, 1955a). These types, 3930A and 3943B, possessing Cocanadas ancestry were tried out at Narasaraopet and Lam for the early, mid and late season sowings, together with improved types from Karunganni, Mathio and Vidarbha tracts. Types 3930A and 3943B proved superior to Cocanadas 2 in respect of ginning and staple length in trials with early season sowing under mixed cropping; they actually recorded full 1" fibre length by sorter (Seshadri Ayyangar, Venkoba Rao and Venkata Reddy, 1956a). Type 3943B has been declared to be capable of spinning up to 40's H.S.W.C.

Mungari (Andhra Pradesh). The *herbaceum* cottons, Westerns, were grown on red and mixed soils of the western part of Rayalaseema tract (Andhra Pradesh) prior to 1910. Later *arboreums*, mainly comprising the *bengalense* types, found an entry into these areas from Vidarbha tract (Bombay State).

They became popular because they were highly productive. Summary of work on the improvement of Mungari cottons prior to 1951 has been presented by Jagannatha Rao, Marar and Santhanam (1953) and an account of work in progress thereafter has been given by Satyanarayana Murthy, Venkoba Rao and Jagannatha Rao (1955a), and Seshadri Ayyangar and Venkoba Rao (1957).

Pure line selection was begun in 1921 at Adoni, using local mixed cotton as the basic material. An *indicum* isolate, strain 274, was obtained by 1930. It, however, could not be distributed because it did not come up to the standard of Westerns 1, the improved *herbaceum* type for the black soil areas of the same tract. Further efforts from 1937 to 1950, resulted in the isolation of the type, Rayalaseema 1, from C.6-3, a strain of Northerns and *cernuum* ancestry obtained from Coimbatore. It was found to be better suited to Mungari areas than the several improved *arboreums* received from the different States of the country and tried out during the same period.

Rayalaseema 1 registered a substantial improvement over the local Mungari cotton in quality ; it could be spun to about 29's H.S.W.C. as against the corresponding value of about 14's given by the local. In quality, it was considered even better than Westerns 1. From the cultivators' point of view, however, the type was somewhat late in maturity and slightly lower in ginning and productivity. The high yielding potential and good fibre quality of strains like the triple hybrid (Northerns, Cocanadas, and *cernuum*) derivatives from Coimbatore (Madras State) was sought to be combined with early maturing habit like that of Jarila from Khandesh tract (Bombay State). The cross of the isolate 2159 representing the former group with Jarila led to the evolution of two types, 3930A and 3943B. They hold much promise since they combine all the desired features of greater productivity, early maturity and better lint quality. They are still under trial.

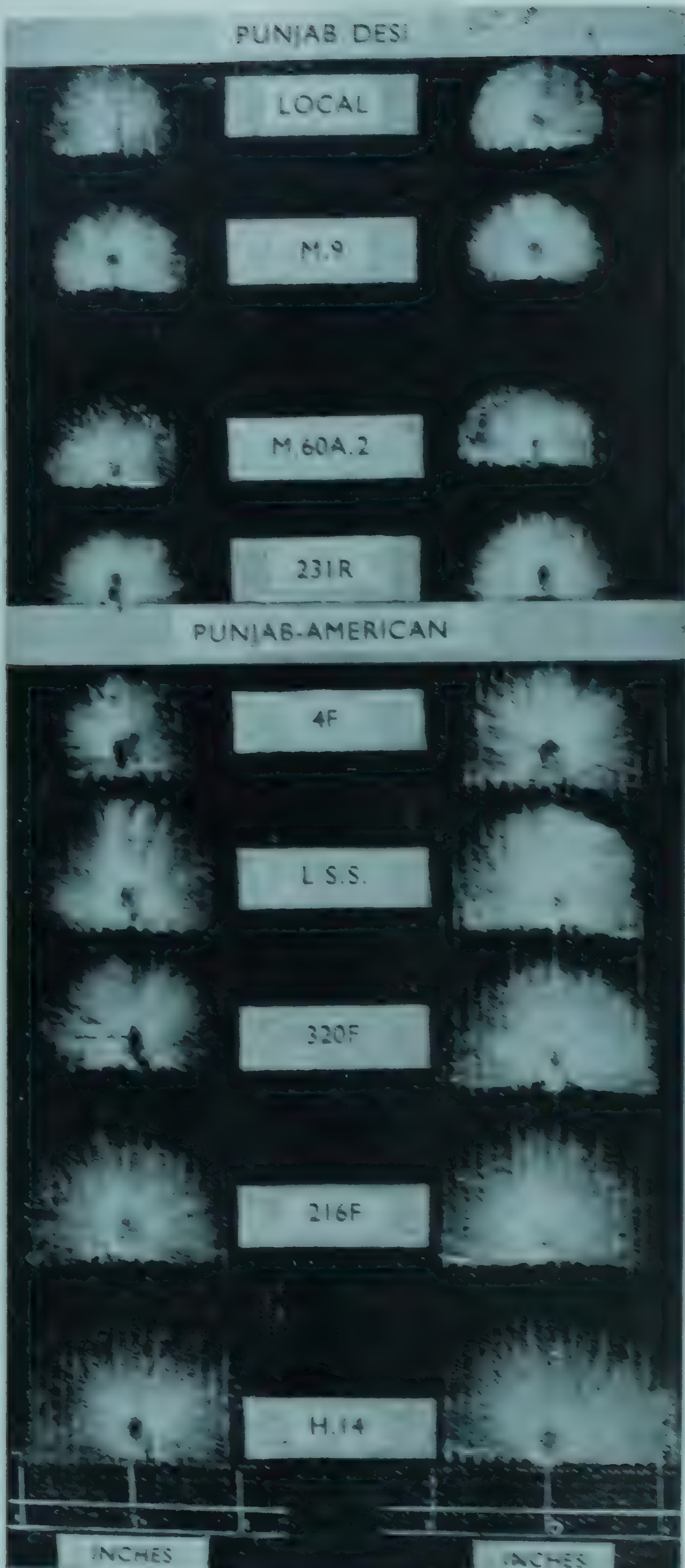
Mungari (Mysore State). In the Mungari areas of Mysore adjoining the similar areas of Andhra Pradesh, a type C.N.4-5 having 37 per cent. ginning, $\frac{3}{4}''$ staple and 20's H.S.W.C. was produced from the cross of the perennial *indicum*, Nadam, with Comilla (*cernuum*) and is under multiplication (Simlote, 1956) (Fig. 25).

Chinnapathi (Andhra Pradesh and Orissa). The original Chinnapathi cotton, also known as Anakapalli White cotton, resembled *bengalense* race in gross morphological features such as, plant habit, leaf shape and flower colour but in anatomical pattern and lint quantity it showed strong affinity with the race *indicum* (Balasubrahmanyan, Mudaliar and Jagannatha Rao 1947). Seshadri Ayyangar, Venkoba Rao and Venkata Reddy (1956b) have classified Chinnapathi under *arboreum* race *indicum* because it shows strong attachment of the fibres to the seed and low ginning value unlike the

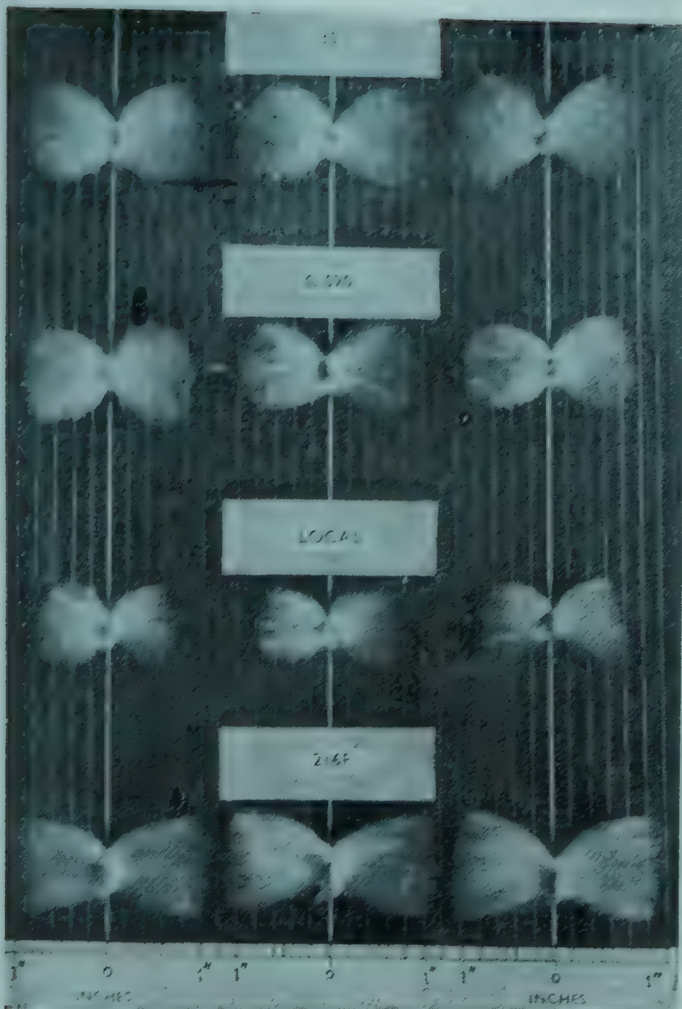
a. 1494

b. 1585

PLATE XXIV

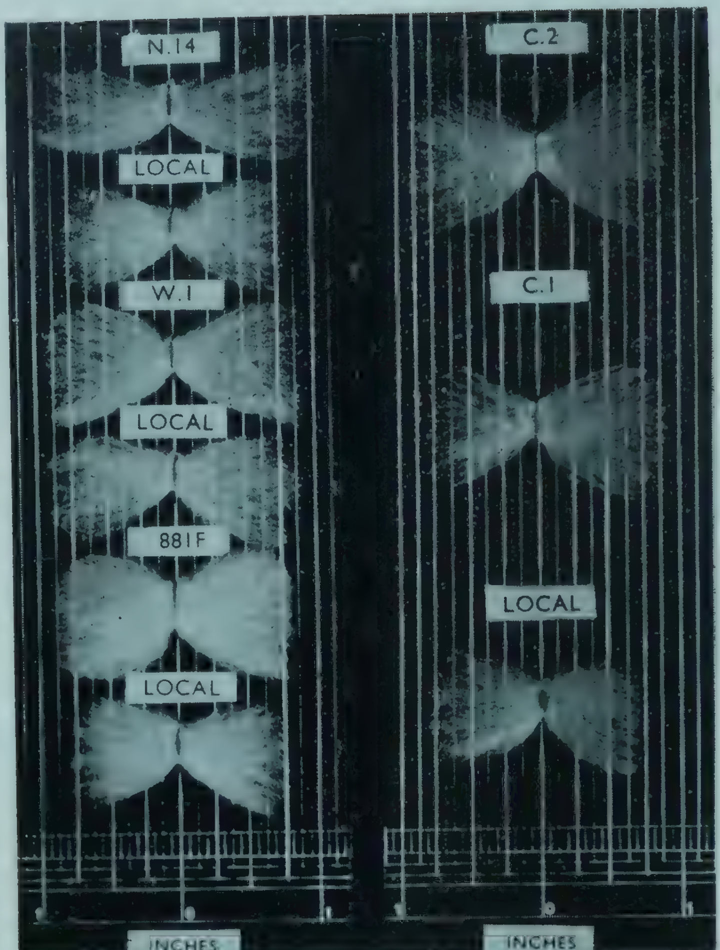


Staple Length of Punjab Desi and American Cottons



a. Staple Length of Uttar Pradesh Cottons

b. Staple Length of Cambodia and Karunganni Cottons



a. Staple Length of Northerns, Westerns and Mungari Cottons

b. Staple Length of Surat Cottons

race *bengalense*. The name Chinnapathi is suggestive of either its short duration as compared to the red lint Cocanadas in the neighbouring tract or the extreme short nature of its fibres.

The efforts made towards the replacement of initial *arboreum* cotton of Chinnapathi tract with better ones evolved from the local material or obtained from the other States, have been surveyed by Seshadri Ayyangar, Venkoba Rao and Venkata Reddy (1956b). The main work was begun by 1945 at Narasaraopet. Single plant selections from local cotton showed very little variability for lint characters ; ginning as low as 25 per cent. and halo length as short as 16 to 18 mm. The coloured cotton, Cocanadas, being late in maturity proved unsuitable for this tract. Search for sympodial (early) types in them was also of no avail. Intra-*arboreum* hybridisation experiments, including Chinnapathi cotton and other types such as Manipur Khaki (*cernuum*), Cutchica 13, Rosea XIII, Jarila, Virnar and Rayalaseema 1 yielded some strains combining earliness and good fibre qualities but they were inconsistent in their yielding ability. Trials are in progress for determining the suitability to the tract of any one of the several improved *arboreums* evolved in other parts of the country. So far, Virnar from Khandesh tract has proved to be the best performer with regard to lint yield in particular, although, as regards spinning value, Pratap from the Mathio tract appeared to be more preferable (Seshadri Ayyangar, Venkoba Rao and Venkata Reddy, 1956b). The types 3930A and 3943B evolved for the Mungari tract have been suggested for trial as substitutes for Chinnapathi cotton (Seshadri Ayyangar, Venkoba Rao and Venkata Reddy, 1956a). Efforts are also under way to introduce H.420 from Vidarbha tract in the Chinnapathi area (Sethi and Dharmarajulu, 1957).

COMILLAS

The reputed coarse cottons of Assam and Tripura belong to *arboreum* race *cernuum* and are known to trade by the names of Comillas, Manipur Khaki or Garo Hill cottons. The non-*cernuum* cottons of Assam belong, according to Silow (1944a), to the race *burmanicum* though for technological and trade reasons they are included under the race *bengalense*. Colour of Assam cotton is black, brown, khaki or creamy white (Barooch and De, 1950). The Comillas are sown by April-May and picked during November to January period.

Breeding work on Comillas was started in 1947 at Tura (Assam). A high ginning and high yielding selection, D.46-2-1, isolated from local *cernuum* cotton has been released for cultivation in the Hills (De and Ganguli, 1953). The Comilla is a dollar earner and apart from the small quantity utilised by the Hill Tribes, the bulk of the produce is exported at a price almost equivalent to the superior long stapled cottons grown in India (Sethi and Dharmarajulu, 1957). The cotton is not utilised in any of the Indian

textile mills and is stated to be taken up by the foreign manufacturers for mixing with wool (Plate IV-b).

PERENNIAL *ARBOREUMS*

Perennial forms of *arboreum* related to the race *burmanicum* are found occasionally throughout the Ganga Valley and the neighbouring regions of Rajasthan and the Punjab. According to Hutchinson (1954), two great annual races arose from this perennial group, the *bengalense* cultigens of India and the *sinense* cottons of China. Hutchinson also states that the Afro-Asian race, *soudanense* too resembles the perennial forms of *burmanicum* cotton, and is of the opinion that the development and spread of all these northern group of *arboreum* races took place in the Indus Valley (Pakistan) in the ancient past.

In the Deccan India, there are three perennial forms of *arboreum* race *indicum*, which continue to be cultivated to a limited extent (Balasubrahmanyan, 1950b). They are Rozi (Kaira district, Gujerat tract, Bombay State), Podupathi or Kondapathi (Visakhapatnam district, Andhra Pradesh) and Nadam (Coimbatore and Salem districts, Madras State). They are inferior in spinning capacity but are known for some special features. Efforts at replacing them with better annuals have not been successful so far. Rozi is more or less immune to root rot. Podupathi is hardy and possesses fibres of good strength. Nadam resists drought and the stem weevil pest (*Pempherulus affinis*). With the opening of the Lower Bhowani Irrigation Project in Madras State, it was proposed to replace Nadam by annual *hirsutum* (Cambodia) cotton as a winter crop (Kalyanaraman, 1955). Earlier Balasubrahmanyan (1950a) had proposed replacing Nadam by the stem weevil-resistant perennial *hirsutums* Moco and Quebradinho belonging to race *marie-galante* or by a similar perennial *barbadense* cotton. The bollworm attack on such perennial cottons was proposed to be kept under control by pruning them once a year in August.

IMPROVEMENT IN INDIVIDUAL CHARACTERISTICS

Yield. The acre yields of seed cotton reported for the different *arboreum* varieties or types grown on experimental farms in their respective regions are compiled in Table 35.

Only a few of the *arboreum* types under distribution at present in different areas, seem to have registered improvement in productivity over the very early types. They are, Maljari (Nimar area), 231 Rosea and 35/1 (Punjab and Uttar Pradesh Bengals), Cocanadas 2 (Cocanadas area) and Rayalaseema 1 (Mungari area). The Oomra types, H.420 (Vidarbha tract), Bhoj (Malwa area) and Gaorani 6 (Gaorani area) appear to have maintained the level of productivity shown by the earlier cottons. In the remaining regions, the current *arboreum* types reveal a comparative deterioration in productivity.

TABLE 35. REPORTED ACRE YIELDS OF SEED COTTON FOR THE DIFFERENT *arboreums* GROWN ON EXPERIMENTAL FARMS (lb. per acre)

Commercial variety	Area	Early types	Value	Value	Later types	References
Oomra	Vidarbha	Verum 262	500	507	*H. 420*	*
	Khandesh	Jadi Mixture	500	615	N. R. 6	Khadilkar, 1950
				676	Banilla, when free from wilt	,,
				481	*Virnar*	*
	Mathio	Jadi Mixture	452	396	*Pratap*	Phadnis, 1957
				474	C. J. 73	,,
	Malwa	Local	380	328 to 378	*Bhoj*	Gadkari, 1954; Simlote, 1956
	Nimar	Local	367	662	*Maljari*	Kocharekar, 1955
	Gaorani	Umri Bani (commercial)	300	426	*Gaorani 6*	*
Bengals	Punjab	Local	900	1168	*231 Rosea*	Anon., 1956a
	Uttar Pradesh	Local	650	763	A. 19	Anon., 1956a:*
				714	*35/1*	Anon., 1956a
Southerns	Karunganni	C.7	483	229	*K. 2*	*
				271	*K. 5*	*
				329	6186-9	Kalyanaraman, Neelakantan and Iyemperumal, 1954
	Northerns	Local	400	273 (100x)	*N. 14*	Anon., 1956a: *
				(113x)	Strain 122	Seshadri Ayyangar, Nageswara Rao and Rama Rao, 1956
	Cocanadas	Local	543	700	*Cocanadas 2*	Jagannatha Rao, Marar and Santhanam, 1953
	Mungari	Local	100*x*	105*x*	*Rayalaseema 1*	Seshadri Ayyangar and Venkoba Rao, 1957

Notes:—The current types are printed in italics. For a particular area, those preceding it in the table are earlier types and those following it are the latest improved types.

References for the character values entered in separate columns are separated by a colon where necessary.

* Technological Reports on Standard Indian Cottons, Indian Central Cotton Committee, Bombay.

TABLE 36. GINNING PERCENTAGE OF THE DIFFERENT *arboreum* COTTONS

Commercial variety	Area	Early types	Value	Value	Later types	References
Oomra	Vidarbha	Jadi Mixture	35	36 to 40	Roseum	†
				30 to 32	Verum 434	*
				31 to 34	*H. 420*	*; Kolte, 1954
				34	*Malini*	Bhatt and Shrivastava, 1956
	Khandesh	Jadi Mixture	35	40·0	N. Roseum 6	Khadilkar, 1950
				34 to 37	*Jarila*	*
				37 to 39	*Virnar*	*
	Mathio	Jadi Mixture	31·6	34·3	*Pratap*	Phadnis, 1957
				34·6	C. J. 73	,,
	Malwa	Local	28·9	31·2 to 32·7	*Bhoj*	Gadkari, 1954; Simlote, 1956
	Nimar	Local	30·2	36·7	*Maljari*	Kocharekar, 1955
	Gaorani	Local	25	30 to 33	*Gaorani 6*	Anon., 1919 : *
				32	*Gaorani 12*	*
				36·8	*Daulat*	Joshi, 1956b
				38·3	1585	Bederker, 1955b
Bengals	Punjab	Local	35	43	*231 Rosea*	Anon., 1956a
	Uttar Pradesh	Local	34	37 to 39	C. 402	Anon., 1956a : *
				36 to 37	*35/1*	† ; Anon., 1956a
Southerns	Karunganni	Local	27·4	30 to 33	*K. 2*	Mollison, 1903 : *
				27 to 31	*K. 5*	*
				31·4	6186-9	Kalyanaraman, Neelakantan and Iyemperumal, 1954
	Northerns	Local	22	22 to 26	*N. 14*	Anon., 1956a : *
				32	Strain 122	Seshadri Ayyangar, Nageswara Rao and Rama Rao, 1956
	Cocanadas	Local	25	30	*Cocanadas 2*	Jagannatha Rao, Marar and Santhanam, 1953
	Mungari	Local	35	33	*Rayalaseema 1*	Seshadri Ayyangar and Venkoba Rao, 1957
				35	3930A	,,

† *Gossypium* Linn. *Wealth of India—Dictionary of Indian Raw Materials and Industrial Products*, Council of Scientific and Industrial Research, New Delhi.
See also note to Table 35.

Virnar of Khandesh tract is far below the preceding higher yielding types N.R.6 and Banilla. Pratap of Mathio tract is a poorer yielder but the recently evolved type C.J.73 of this region seems to be very promising in this regard.

Ginning Percentage. The ginning value of *arboreum* cottons in India ranges from *c.* 22 to 56 per cent. (Table 36). Comilla cotton belonging to race *cernuum* gins to *c.* 47 per cent. or even more (Anon., 1956a; Barooch and De, 1950). The *bengalense* and the *indicum* types occupy the second and the third positions, respectively, in regard to this character. Within *bengalense* cottons those possessing white flowers and narrow central leaf lobes, i.e., *roseums* like Roseum, N. Roseum 6 and 231 Rosea, show higher ginning (36 per cent. to 43 per cent. Table 36). *Cernuum* and *roseum* cottons have, therefore, been used in hybridisation experiments, wherever necessary, for improving the ginning character of *arboreum* cottons of different tracts. The ginning values of the early and recent *arboreum* cottons are presented in Table 36 from which inferences regarding the extent of improvement, if any, effected in this character, can be drawn.

Selection alone has led to the isolation of better ginning *arboreum* types in most of the regions in the country. The tracts where such selections are still under cultivation are Gaorani (Gaorani 6, Gaorani 12 and Daulat), Uttar Pradesh (35/1), Mathio (Pratap), Malwa (Bhoj), Northerns (N.14) and Cocanadas (Cocanadas 2). The ginning values of N.14 and Bhoj are much lower than those of the other selections. On the other hand, mere selection has remarkably stepped up the ginning in Gaorani cottons as in the strain 1585 from 25·0 to 38·3 per cent. (Bederker, 1955).

In Khandesh tract, ginning value of the Verum (yellow-flowered *bengalense* with narrow central leaf lobes) cotton, Jarila was improved upon by hybridisation with a *roseum* type, N.R. 5 having 44 per cent. ginning (Khadilkar, 1950). The type Virnar obtained from this hybridisation approaches the ginning value of an earlier high ginning type of the tract, N. Roseum 6. Jarila itself is responsible for the improved ginning value of the Nimar cotton, Maljari (Kocharekar, 1955). Among Uttar Pradesh *arboreums*, the type C. 402, having *roseum* and *cernuum* ancestry, was the best ginner. The current type, 35/1, evolved by selection alone, is a little inferior to C.402 in this regard, though it still shows an improvement over the original local *arboreum* of the region. The types or strains K.2, K.5 and 6186-9 of Karunganni tract and 122 of Northerns tract owe their improvement in ginning to *cernuum* ancestry.

Fibre Length. All the present types of *arboreum* cottons in India, excluding those of the Punjab Bengals and Comillas, have registered a considerable improvement over the local in mean fibre length (Tables 37 and 50).

The current type of Khandesh tract, Virnar and the latest improved strain of Mathio tract, C.J.73, possessing mean fibre length values 0·88″ and 0·907″, respectively, are the best among the *bengalense* cottons in this

respect. Bhoj of Malwa tract, also a *bengalense* cotton, shows improvement over the local in fibre length but it is a little inferior to an earlier type, Malvi 9, of the same region. Selections from Gaorani (Gaorani 6: 0·83″; Gaorani 12: 0·90″ and 1494: 0·98″), Northerns (N. 14: 0·89″) and Cocanadas (Cocanadas 2: 0·89″) are among the leading *indicum* types in fibre length. From among the *indicum-cernuum* hybrid derivatives, those having long fibres are: 6186-9 (0·95″) of Karunganni tract and H.420 (*c.* 0·88″) of Mungari tract. Mean fibre length of the latest strain of Mungari tract, 3943B is 0·98″; this strain has *indicum-bengalense-cernuum* heritage.

Recently, Gaorani selections (Bederker, 1956) and Karunganni strains (Iyengar and Santhanam, 1956) possessing fibres 1″ or more in length have been isolated.

Fibre Weight. Coarser the fibre greater is its fibre weight per unit length. The coarsest *arboreum* is the Comilla cotton belonging to race *cernuum*. Its mean fibre weight per inch is $0{\cdot}380 \times 10^{-6}$ oz. (Table 38). Similar fibre weight values for some of the early and recent types are given in Table 50.

It will be seen that the finest (C.J.73 of Mathio tract) and the coarsest (231 Rosea of the Punjab) non-*cernuum arboreum* representatives are met within the race *bengalense*. The current types H.420 (Vidarbha tract), Maljari (Nimar tract), 231 Rosea (Punjab), K.5 and 6186-9 (Karunganni tract) and Cocanadas 2 (Cocanadas tract) show an increase in fibre weight per unit length over the earlier types. In the Northerns, Gaorani and Karunganni tracts, the types N.14, G.12 and K.2, respectively, do not show any appreciable change in their fibre weight per inch as compared to some of the early types of their regions. The current type of Uttar Pradesh, 35/1, possesses fibres finer than those of the original local cotton but distinctly coarser than those of one of the early improved types, C.402. All the remaining recent *arboreum* types have registered a decrease over the earlier types of their regions in respect of fibre weight per inch which is a desirable feature.

Recently, Bederker (1956) has reported isolation of Gaorani strains possessing as low as $0{\cdot}123 \times 10^{-6}$ oz. mean fibre weight.

Spinning Capacity. Among the non-*cernuum arboreum* cottons with which breeding work has been done, all excepting the Punjab Bengals have registered marked improvement in their spinning capacity (Table 39).

The *indicum* selection, N.14 of Northerns tract is the oldest and one of the leading improved types in respect of spinnability. Similar high spinning *indicum* selections have also been isolated in Gaorani and Cocanadas tracts. The latest *bengalense* type, C. J. 73 of Mathio tract is reported to bear a similarly high spinning value. Derivatives from *indicum-cernuum* hybrids, improved in their spinning capacity have been released for Karunganni, Vidarbha and Mungari tracts. In Vidarbha tract one of the earlier *bengalense* types, Late

TABLE 37. MEAN FIBRE LENGTH OF THE DIFFERENT *arboreum* COTTONS

Commercial variety	Area	Early types	Value (inches)	Value (inches)	Later types	References
Oomra	Vidarbha	Verum 262	0·816 to 0·827	0·87 to 0·88	*H. 420*	*; Kolte, 1954
	Khandesh	Jadi Mixture	0·50	0·85	*Jarila*	Khadilkar, 1947a:*
				0·88	*Virnar*	*
	Mathio	Jadi Mixture	0·80	0·85	*Pratap*	Phadnis, 1957
				0·907	C. J. 73	,,
	Malwa	Local	0·70	0·79 to 0·85	Malvi 9	Gadkari, 1954; Simlote, 1956
				0·77	*Bhoj*	,,
	Nimar	Local	0·83	0·86	*Maljari*	Kocharekar, 1955
	Gaorani	Umri Bani	0·821	0·831	*Gaorani 6*	*
				0·90	*Gaorani 12*	*
				0·98	1494	Bederker, 1955b
Bengals	Punjab	Local	(19/32)	(20/32)	*231 Rosea*	Anon., 1956a
		39 Mollisoni	0·73	0·67	*M. 60-A·2*	*: Negi and Avtar Singh, 1956
	Uttar Pradesh	Local	0·70	(0·82)	*35/1*	*:†
Southerns	Karunganni	C. 7	0·836	0·87	*K. 2*	*
				0·898	*K. 5*	*
				0·95	6186-9	Kalyanaraman, Neelakantan and Iyemperumal, 1954
	Northerns	Local	(26/32 to 28/32)	0·894	*N. 14*	Anon., 1956a:*
	Cocanadas	Local	0·79	0·89	*Cocanadas 2*	Jagannatha Rao, Marar and Santhanam, 1953
	Mungari	Local	0·80	0·88	*Rayalaseema 1*	Seshadri Ayyangar and Venkoba Rao, 1957
				0·98	3943 B	,,

See notes to Tables 35 and 36.
Staple length values are within parenthesis.

TABLE 38. MEAN FIBRE WEIGHT PER INCH (10^{-6} oz.) OF THE DIFFERENT *arboreum* COTTONS

Commercial variety	Area	Early types	Value	Value	Later types	References
Oomra	Vidarbha	Verum 262	0·176 to 0·180	0·173 to 0·187	*H. 420*	*; Kolte, 1954
	Khandesh	N. Roseum 6	0·262	0·165	*Jarila*	Khadilkar, 1950:*
				0·181	*Virnar*	*
	Mathio	Jadi Mixture	0·198	0·167	*Pratap*	Phadnis, 1957
				0·154	C. J. 73	,,
	Malwa	Local	0·199	0·163	*Bhoj*	Gadkari, 1954; Simlote, 1956
	Nimar	Local	0·156	0·174	*Maljari*	Kocharekar, 1955
	Gaorani	Umri Bani	0·172	0·162	*Gaorani 6*	*
				0·171	*Gaorani 12*	*
				0·157	1494	Bederker, 1955b
Bengals	Punjab	Local	0·310	0·291	*M. 60-A·2*	Anon., 1956a: Negi and Avtar Singh, 1956a
				0·324	*231 Rosea*	Anon., 1956a
	Uttar Pradesh	Local	0·250	0·188	C. 402	Anon., 1956a:*
				0·211	*35/1*	Anon., 1956a
Southerns	Karunganni	C. 7	0·171	0·169	*K. 2*	*
				0·180	*K. 5*	*
				0·187 to 0·200	6186-9	Kalyanaraman, Neelakantan and Iyemperumal, 1954
	Northerns	Local	0·168	0·168	*N. 14*	Anon., 1956a:*
	Cocanadas	Local	0·174	0·194	*Cocanadas 2*	Jagannatha Rao, Marar and Santhanam, 1953
				0·190	R. H. 25	,, ,,
	Mungari	Local	0·222	0·192	*Rayalaseema 1*	Seshadri Ayyangar and Venkoba Rao, 1957
				0·173	3943 B	,,

See notes to Tables 35 to 36.

TABLE 39. SPINNING CAPACITY OF THE DIFFERENT *arboreum* COTTONS

Commercial variety	Area	Early types	H.S. W.C.	H.S. W.C.	Later types	References
Oomra	Vidarbha	Verum 262	22·6	30·6	Late Verum	*
				31·2	*H. 420*	Kolte, 1954
				26·7	,,	*
				39w	*Malini*	Bhatt and Shrivastava, 1956
	Khandesh	N. Roseum 6	6	29·5	*Jarila*	Khadilkar, 1950:*
				28·7	*Virnar*	*
	Mathio	Jadi Mixture	15	28	*Pratap*	Phadnis, 1957
				38	C. J. 73	,,
	Malwa	Local	12	21	*Bhoj*	Gadkari, 1954; Simlote, 1956
	Nimar	Local	26	30	*Maljari*	Kocharekar, 1955
	Gaorani	Umari Bani	27·9	32·3	*Gaorani 6*	*
				39	*Gaorani 12*	*
				39	1494	Bederker, 1955b
Bengals	Punjab	39 Mollisoni	8	6w m. s.	*231 Rosea*	*: Anon., 1956a
	Uttar Pradesh	Local	10	18·2	C. 402	Sethi and Ansari, 1943:*
				13 to 19w	*35/1*	
Southerns	Karunganni	C. 7	25·2	29·7	*K. 2*	*
				30·2	*K. 5*	*
				34 to 36	6186-9	Kalyanaraman, Neelakantan and Iyemperumal, 1954
	Northerns	Local	22w m. s.	36·7 32w m. s.	*N. 14*	Anon., 1956a;*
	Cocanadas	Local	25	35	*Cocanadas 2*	Jagannatha Rao, Marar and Santhanam, 1953
	Mungari	Local	14	29	*Rayalaseema 1*	Seshadri Ayyangar and Venkoba Rao, 1957
				40	3943 B	,,

See notes to Tables 35 and 36.
w: Approximate warp count.
m. s.: Mill spinning.

Verum released for the eastern part of the region was also a good spinner. The latest *arboreum* strain, 3943B of Mungari tract, possessing *indicum-cernuum-bengalense* heritage appears to be a very promising type in regard to spinning capacity.

On studying the spinning performance of the types in relation to their fibre length and fineness (Tables 37, 38 and 39), it will be seen that many of the recent *arboreum* types (Jarila, Pratap, C.J.73, Bhoj, Gaorani 6, 1494, K.2, Rayalaseema 1 and 3943B) show simultaneous improvement in all these attributes of the fibre. Improvement in fibre length alone accounts for improved spinning in the other types; in the types Maljari, Daulat, 35/1, K.5, 6186-9 and Cocanadas 2, this improvement is despite the increase in fibre weight per unit length. H.420 and Virnar are reported to be a little inferior in spinnability as compared to the earlier types, Late Verum and Jarila, respectively, of their regions; their increased fibre weight per unit length is probably the reason of their slightly impaired spinnability.

Lately, Bederker (1956) has reported on the isolation of Gaorani strains which as a result of further increase in halo and fibre length and decrease in fibre weight per unit length, are estimated to spin to as high as 60′s.

Improvement of Gossypium herbaceum Cotton

Nearly 29 per cent. of the total cotton produced in the country is represented by *herbaceum* race *wightianum*. As in the case of *arboreum* cottons, the *herbaceums* too are recognised by different trade names in different parts of the country. The important *herbaceum* cottons are: Wagad, Broach and Surti grown in Kutch, Kathiawar and Gujerat regions of Bombay State, Kumptas grown in Mysore State and Westerns cultivated mainly in the western part of Rayalaseema tract, Andhra Pradesh. All these *herbaceums* are grown under rainfed conditions. In Bombay State, the *herbaceums* are grown in black or coastal alluvial soils and in the south they are grown either on black soils or on red laterites. Sowing period of Wagad extends from June to August, whereas that of Broach and Surti is during June-July; all these three cottons are picked during January-March. Kumptas and Westerns are sown during August-September but the former are picked during February-April and the latter during January-May. Thus, the growing period of Kumptas is less by about one to two months as compared to that of the other Indian *herbaceums*.

Cultivation of some of the other Indian *herbaceum* cottons is either on a very small scale or has been abandoned altogether. Lalio of North Gujerat and South Kathiawar regions, being late in maturity, often suffered from frost attack. With the beginning of the present century, it began yielding ground to the early maturing, frost escaping, Mathio (*arboreum*) cotton in South Kathiawar and to the closed boll types, Wagad and improved Broach types in North Gujerat. Lalio is now an obsolete cotton. Goghari, a high ginning, inferior quality *herbaceum* of obscure origin, got introduced into middle Gujerat in

1875, and formed a major component of the mixed cotton Kanvi (also known as Broach Local) until the end of the First World War. It has since been replaced by improved Broach types. Original White Northerns of the black soil areas of the eastern part of Rayalaseema tract (Andhra Pradesh) were predominantly *herbaceum* cottons; the other major constituent was the red lint *arboreum*. These White Northerns were poor in quality and have been largely replaced by the improved white lint *arboreum* type, Northern 14. The inferior quality *herbaceum*, Uppam of Madras State, has almost been substituted by the improved *arboreum* types evolved for the Karunganni tract.

Breeding work done on the important *herbaceums* in India will now be taken up for review.

Surti (Bombay State). The reputed fine quality Surti Local cotton also known as Surti-Broach or even as Broach Desi (Patel, G. B., 1947) owes its name to the port Surat, located in South Gujerat.

The Government Agricultural Research Station was set up at Surat as early as in 1896. Work carried out on the improvement of *herbaceum* cotton in this region since then has been reviewed by Patel (1947). Selection from Surti Local, 1A Long Boll, showed *c.* four per cent. higher ginning. This type was later partly replaced by 1027A Long and Fine (1027A L.F.) evolved from the cross of Goghari made at Kirkee Farm (near Poona) with Kumpta cotton in 1901. This new type registered an improvement over 1A Long Boll in staple and silky feel of the fibres but in regard to ginning percentage it showed reversion towards the level of Surti Local. To remedy this situation, 1027A L.F. was crossed with the high ginning parent, 1A Long Boll and a variety Suyog, retaining to a large measure the fibre qualities of 1027A Long and Fine, excepting silkiness, and incorporating, in addition, higher ginning quality, was evolved.

Lately, variety Vijalpa has been produced from the cross (Vijay x 1027 A L.F.) by backcrossing to the mother parent (Pandya, Majumdar and Desai, 1956). It has registered improvement in yield of cotton and is also early and wilt-resistant. Suyog being rather late maturing succumbs to drought in this region; it also shows susceptibility to wilt. Vijalpa is, therefore, favoured instead; it has covered the whole of South Gujerat now (Anon., 1956a) (Plates V-b and XXVI-b).

Broach (Bombay State). Broach Desi was the original superior quality cotton of middle Gujerat, named after the main town in the region. With the admixture of Goghari, it deteriorated in quality. Work on its improvement has been reviewed by Patel, P.L. (1947) and Thakar (1955).

The Goghari component of Broach Local stepped up its ginning value but brought down its fibre quality. Moreover, Goghari showed wilt susceptibility also. Research on cotton improvement started with the establishment of experimental farms at Broach in 1913. From the Broach Local mixture,

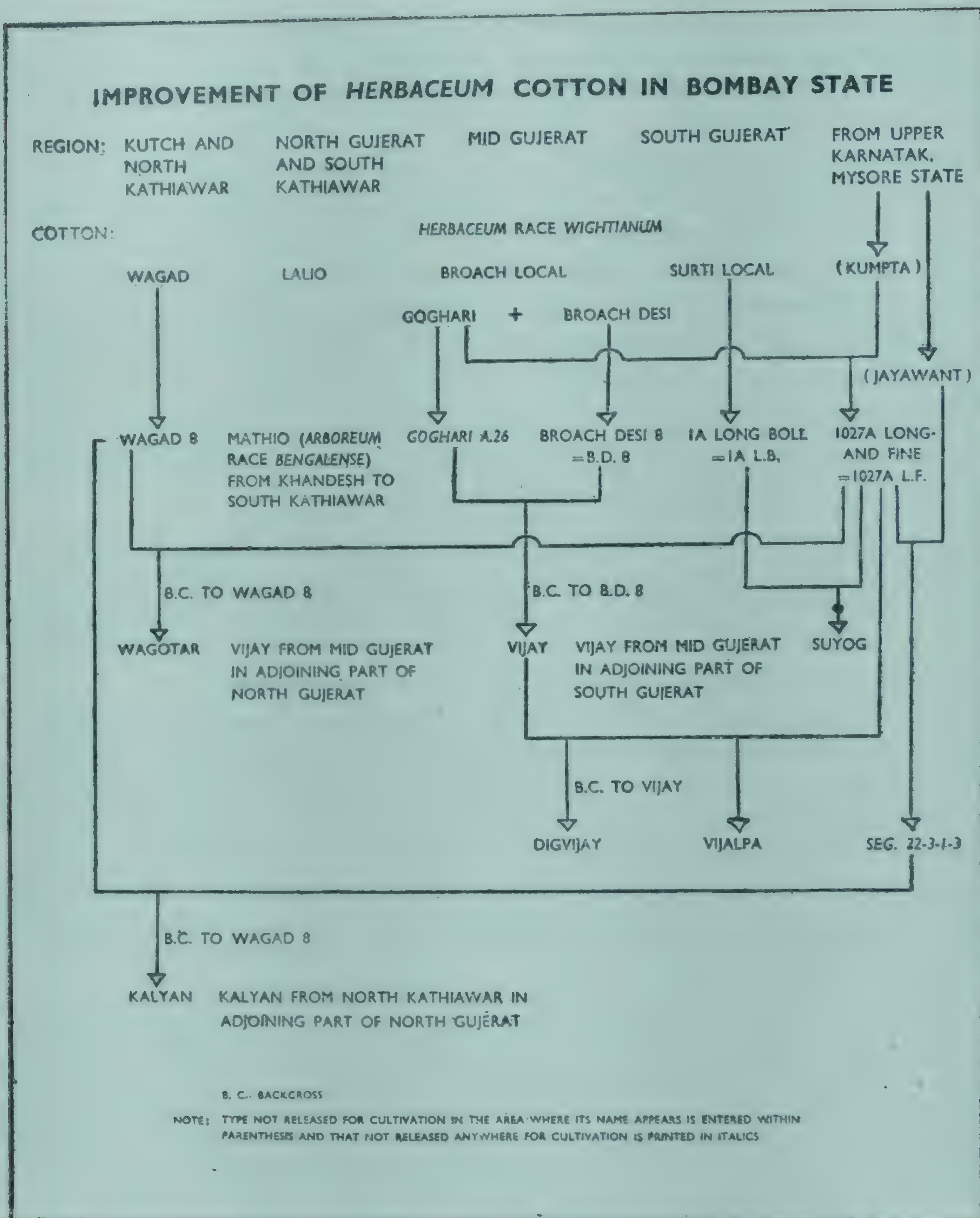


Fig. 26. Improvement of *herbaceum* Cotton in Bombay State

selections of Goghari having high ginning (42 to 47 per cent.) but low spinning value (8 to 12 H.S.W.C.) and one selection of Broach Desi (B.D.8) combining high spinning value (H.S.W.C. 38.5) with wilt resistance but possessing a low ginning outturn (*c.* 34 per cent.), were isolated. Improvement in ginning percentage of the Broach Desi selections was sought to be made by hybridising them with Comilla (*arboreum* race *cernuum*), Wagale (*arboreum* race *burmanicum*) and Goghari selections. The variety Vijay, fulfilling the combined requirements of growers, ginners and mill industry in respect of yield, ginning outturn and fibre quality, was evolved from the cross (B.D.8 x Goghari A.26) after backcrossing to B.D.8. This variety covered the whole of middle Gujerat and the eastern part of North Gujerat. It also penetrated into South Gujerat a little. Considering yield alone, it is slightly inferior to Broach Local but distinctly superior to B.D.8. It inherits its fibre qualities and wilt resistance from B.D.8 and high ginning from Goghari A.26 (Plate XXVII-a).

Attempts were made to improve staple length in Vijay further and also to incorporate early maturing habit. For this purpose, 1027A L.F. from Surat was used in crosses with Vijay and a type named Digvijay has been evolved by backcrossing to Vijay. Digvijay has been released for general cultivation in 1956 because, comparatively it spins two to three counts more and yields about 20 lb. more of seed cotton.

Wagad (Bombay State). Wagad cotton, bearing practically indehiscent ripe bolls, has been named after the Kutch port through which it is presumed to have been introduced. This cotton probably originated from the perennial and late types from Baluchistan, possessing indehiscent bolls like those of Wagad. Work on improvement of Wagad cotton has been summarised by Patel (1949).

Selection from the local material, resulted in the isolation of Wagad 8. It showed 11 per cent. increase in yield of cotton and four per cent. in ginning outturn over the local. Quality of lint, however, was poor. Improvement in lint quality was achieved on hybridising Wagad 8 with 1027A L.F. evolved for South Gujerat and segregate 22-3-1-3 obtained at Surat from the cross (1027A L.F. x Jayawant). In these two cases of hybridisation backcrosses were made with Wagad 8 and the types obtained were Wagotar and Kalyan, respectively; the latter having succeeded the former. Wagad types were also crossed with long stapled and closed boll races from Persia and early types from Russia. Synthetic types obtained, from these crosses did not prove superior to Kalyan, evolved simultaneously with them. Wagotar recorded 11 per cent. increase in lint yield over Wagad, although in respect of seed cotton yield it was inferior to the latter. Kalyan proved superior to the local in its yield of *kalas* (ripe dry bolls), seed cotton and lint. It has spread to the eastern part of Wagad tract and western part of North Gujerat (Fig. 26 and Plates V-a and XXVII-b).

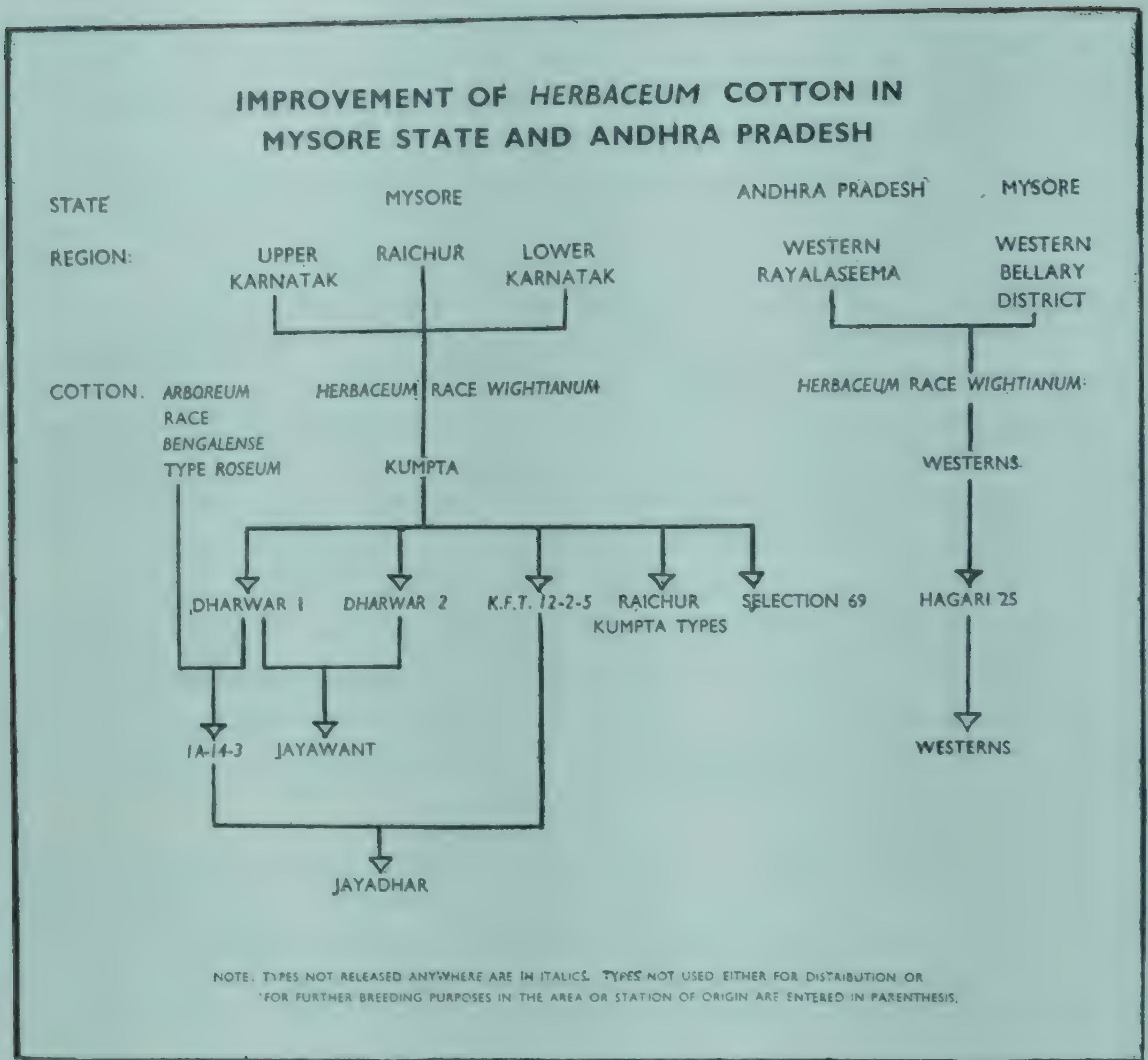


Fig. 27. Improvement of *herbaceum* Cotton in Mysore State and Andhra Pradesh

Kumpta (Mysore State). The bulk of *herbaceum* cottons of Mysore State is known to trade by the name Kumpta because it is shipped from the harbour of this name to Bombay market. As distinct from the bright white lint of *herbaceums* of Bombay State, Kumptas have a dull red tinged lint.

Work on the improvement of Kumpta cotton in the northern part of Mysore State was begun in 1905 at Dharwar; the achievements have been recorded by Prayag (1942), Kelkar, Choudhari and Hiremath (1947b), Patil (1948) and Tippannavar and Patil (1952). By selection, types Dharwar 1 and Dharwar 2 were isolated from the local bulk of the northern part of Kumpta tract. Dharwar 1 proved superior in ginning, staple length and spinning quality but was susceptible to wilt whereas Dharwar 2 showed resistance to wilt but was inferior in economic characters. The two types were inter-crossed and the variety Jayawant, combining the good attributes from either of the parents was evolved.

Another highly wilt-resistant selection from Kumpta Local was K.F.T. 12-2-5. It was isolated under artificial infection conditions arranged in a green house. It was also high yielding and its lint could be spun to 44's warps but it was low in ginning value. Earlier some high ginning, though wilt-susceptible segregates were obtained by crossing Dharwar 1 with *arboreum* race *bengalense* type *roseum* known for higher ginning value. One of the segregates (1A-14-3), earlier in maturity, was crossed with the aforementioned selection K.F.T.12-2-5 and the variety Jayadhar combining desirable features from either of the parents was evolved. This new variety Jayadhar being superior to Jayawant in yield and other economic features, has dominated the Kumpta tract at present (Plate XXVIII-a).

In Raichur district of Mysore State, the improved *herbaceum* type bred out was Raichur-Kumpta 19 (R.K. 19)—(Sethi and Dharmarajulu, 1957).

In the southern part of Kumpta tract of Mysore State, selection work on local *herbaceum* material was independently carried out since 1917. The strain, Selection 69, thus evolved showed suitability for the region and proved distinctly superior to the local in ginning value (Anon., 1956a) (Plates VI-b and XXVIII-b).

Westerns (Andhra Pradesh and Mysore States). About 56 per cent. of Westerns cotton is cultivated in the western part of Rayalaseema tract of Andhra Pradesh and the rest in the adjoining part (Bellary district) of Mysore State. Breeding work on the Westerns cotton was initiated as early as in 1908 at Hagari ; this station is now located in Bellary district of present Mysore State. Hagari 25 (H.25) was the first type isolated by selection. Reselection exercised on H.25 led to the evolution of the variety, Westerns 1. The original Westerns cotton spun to only 20's and gave ginning outturn of about 25 per cent.; Westerns 1 spins to about 29's and possesses about 28 per cent. ginning value (Satyanarayana Murthy, Venkoba Rao

and Jagannatha Rao, 1955b). General distribution of Westerns 1 began in 1926-27 (Anon., 1956a) (Fig. 27).

IMPROVEMENT IN INDIVIDUAL CHARACTERISTICS

Yield. The figures reported for the acre yields of seed cotton from the various *herbaceum* types grown on experimental farms situated in their areas of cultivation are presented in Table 40.

TABLE 40. REPORTED ACRE YIELDS OF SEED COTTON FROM THE DIFFERENT *herbaceum* COTTONS GROWN ON EXPERIMENTAL FARMS (lb. per acre)

State	Commercial variety	Early unimproved cotton	Value	Value	Latest types	References
Bombay Gujerat tract	Surti	Local	505	523	*Vijalpa*	Pandya, Majumdar and Desai, 1956
,,	Broach	Local	581	546	*Digvijay*	Patel, P. L., 1947: Thakar, 1955
,,	Wagad	Local	424	637	*Kalyan*	Patel, 1949
Mysore	Kumpta	Local	524	651	*Jayadhar*	Tippannavar and Patil, 1952:*
				280	*Selection 69*	Anon., 1956a
Andhra Pradesh and Mysore	Westerns	Local	(*c.* 208) (commercial)	231	*Westerns 1*	Anon., 1919:*

See notes to Tables 35 and 36.

Kalyan (Wagad) and Jayadhar (Kumpta) appear to have registered marked improvement in yielding capacity over the original cottons of their region. Digvijay of middle Gujerat area still falls short of the original cotton, Broach Local, in productivity and Vijalpa of South Gujerat and Westerns 1 of Westerns tract appear to have maintained the yielding potential possessed by the earliest cotton of their respective zones.

Ginning Percentage. Among the Indian *herbaceum* cottons, Goghari introduced into middle Gujerat by 1875, processes the highest ginning value; some of its selections range from 42 to 47 per cent. in ginning outturn (Patel, P. L., 1947). Next to Goghari come the Wagad *herbaceums* of Kutch, Kathiawar and North Gujerat in this respect. The Kumpta and the Westerns *herbaceums* are inferior to the *herbaceums* of Gujerat region as a whole* in ginning. The ginning values thus range from *c.* 23 to 47 per cent. (Table 50) ; those of some of the early and the recent *herbaceums* of India are given in Table 41.

* Kutch and Kathiawar may be considered as constituting the northernmost part of the whole of Gujerat tract.

TABLE 41. GINNING PERCENTAGE OF THE DIFFERENT *herbaceum* COTTONS

State	Commercial variety	Early unimproved cotton	Value	Value	Later improved types	References
Bombay Gujerat tract	Surti	Local	34·8	39	1A Long Boll	Pandya, Majumdar and Desai, 1956: Patel, G. B., 1947
				36	*Vijalpa*	,,
,,	Broach	Local	41·6	41·2	*Vijay*	Patel, P. L., 1947
				38·8	*Digvijay*	Thakar, 1955
,,	Wagad	Local	34·4	33 to 43	Wagad 8	Patel, 1949:*
				39·9	*Kalyan*	,,
Mysore	Kumpta	Local	25·4	*c.* 29 to 32	*Jayadhar*	Tippannavar and Patil, 1952:*
				28 to 29	*R. K. 19*	†
				30	*Selection 69*	†
Andhra Pradesh and Mysore	Westerns	Local	*c.* 25	*c.* 28 to 32	*Westerns 1*	Anon., 1919:*

See notes to Tables 35 and 36.

In South Gujerat, the type under distribution at present is Vijalpa. It owes its high ginning value to Goghari ancestry. An earlier cotton 1A L. B., evolved by selection from the local cotton of the same region, showed still greater ginning value. Digvijay, a sister strain of Vijalpa, distributed in the middle Gujerat region is inferior to the original mixed cotton of this tract, comprising Broach Desi and Goghari, in respect of ginning outturn. In North Gujerat, the latest Wagad type, Kalyan, shows improvement over the local in ginning outturn although it is a little inferior to an earlier type Wagad 8, selected from the local, in this respect. Jayadhar, latest Kumpta cotton, owes its increased ginning to *arboreum* (*roseum*) ancestry whereas a similarly high ginning value has been attained in Westerns cotton by selection alone, as in the case of Westerns 1.

Fibre Length. Fibre length of all the current *herbaceum* types is better than that of the local types of their respective regions in the country (Tables 42 and 50).

Vijalpa and Westerns 1 are a little inferior to their immediate predecessors, Suyog and Hagari 25, in this respect, in Surti and Westerns tracts, respectively. Kumpta blood is to be found in all the recent *herbaceum* types of Gujerat. Suyog of Surti tract in Gujerat, possesses the longest fibres (0·97″); it has both Kumpta and Surti heritage. *Herbaceum* strains having fibres 1″ or more in length have recently been reported from Gujerat (Pandya, Majumdar and Desai, 1956).

Fibre Weight. All the recent *herbaceum* types possess finer fibres ; their fibre weight per unit length is lesser than that of the early types in their zones (Tables 43 and 50).

Digvijay of Broach tract in Gujerat, originating from Kumpta and Broach *herbaceum* ancestry, possesses the least fibre weight, $0 \cdot 147 \times 10^{-6}$ oz. per inch. Reduction in fibre weight per unit length in Wagad types, Wagotar and Kalyan, has been achieved by resorting to hybridisation with Kumpta cottons. Kalyan is still the coarsest among the present day *herbaceums* in India. Goghari *herbaceum*, which was a component of the mixed cotton of middle Gujerat till the twenties, is the coarsest cotton of this species.

Spinning Capacity. All the latest *herbaceum* types in India show greatly improved spinning as compared to the early local *herbaceums* of their respective regions (Table 44). Digvijay of Gujerat tract and Jayadhar of Kumpta tract are the leading types in this respect. In majority of these current types conjoint improvement in length and fineness of fibres has led to concomitant amelioration of spinning quality (Tables 42, 43, 44 and 50). In the types Vijalpa and Westerns 1, however, improvement in spinning over their predecessors Suyog and Hagari 25, respectively, is due to increase in fibre length more than counter-balancing the adverse effect of increase in fibre weight.

TABLE 42. MEAN FIBRE LENGTH IN THE DIFFERENT *herbaceum* COTTONS

State	Commercial variety	Early types	Value (inches)	Value (inches)	Later types	References
Bombay Gujerat tract	Surti	Local	0·85	0·97	Suyog	Pandya, Majundar and Desai, 1956:*
				9·94	*Vijalpa*	,,
	Broach	Local	0·75	0·91	*Digvijay*	Patel, P. L., 1947: Thakar, 1955
	Wagad	Local	0·80	0·85	*Kalyan*	Patel, 1949
Mysore	Kumpta	Local	0·83	0·918	*Jayadhar*	Tippannavar and Patil, 1952:*
				(0·81)	*R. K. 19*	†
Andhra Pradesh and Mysore	Westerns	Hagari 25	0·873	0·859	*Westerns 1*	*

TABLE 43. MEAN FIBRE WEIGHT PER INCH (10^{-6} oz.) IN THE DIFFERENT *herbaceum* COTTONS

State	Commercial variety	Early types	Value	Value	Later types	References
Bombay Gujerat tract	Surti	Local	0·232	0·170	*Vijalpa*	Pandya, Majumdar and Desai, 1956
	Broach	Local	0·220	0·147	*Digvijay*	Patel, P. L., 1947: Thakar, 1955
	Wagad	Local	0·211	0·182	*Kalyan*	Patel, 1949
Mysore	Kumpta	Local	0·193	0·176	*Jayadhar*	Anon., 1956a:*
				0·180	*Selection 69*	Anon., 1956a
Andhra Pradesh and Mysore	Westerns	Hagari 25	0·182	0·174	*Westerns 1*	*

TABLE 44. SPINNING CAPACITY OF THE DIFFERENT *herbaceum* COTTONS

State	Commercial variety	Early unimproved cotton	H. S. W.C.	H.S. W.C.	Latest types	References
Bombay Gujerat tract	Surti	Local	20 to 24	37	*Vijalpa*	Pandya, Majumdar and Desai, 1956
	Broach	Local	13	43	*Digvijay*	Patel, P. L., 1947: Thakar, 1955
	Wagad	Local	14·5	27	*Kalyan*	Patel, 1949
Mysore	Kumpta	Local	24	43	*Jayadhar*	Tippannavar and Patil, 1952:*
				24w	*R. K. 19*	†
				32w	*Selection 69*	†
Andhra Pradesh and Mysore	Westerns	Local	20w	29·8	*Westerns 1*	Anon., 1919

See notes to Tables 35, 36, 37 and 39.

Introduction and Acclimatisation of Gossypium hirsutum and Gossypium barbadense Cotton

The superior quality long staple cottons belonging to the New World tetraploid species, *hirsutum* and *barbadense*, have been introduced into India from time to time, since 1790. A perennial cotton, Bourbon, belonging to *hirsutum* race *punctatum* was first introduced into South India in 1790 by the British East India Company. On acclimatisation, it soon formed trade component of Salems cotton grown on the poor light red soils of Coimbatore and Salem districts of Madras State ; the other component of Salems being the *arboreum* cotton, Nadam (Anon., 1954). Cultivation of Bourbons in this region is at present on a very small scale (Anon., 1956a) and proposals to replace them with perennial forms belonging to *hirsutum* race *marie-galante* (Moco and Quebradinho) or *barbadense* (Balasubrahmanyan, 1950a), or with annual Cambodias belonging to *hirsutum* race *latifolium* (Kalyanaraman, 1955) have already been made (Plate XXIX-a).

Bourbons are also well acclimatised to the severe summer droughts and the heavy monsoons of the South Kanara region of Mysore State (Balasubrahmanyan, 1950a). Moco was found to be suitable for growing on the cultivable wastes or in the backyards, or for intercropping in coconut, arecanut, pepper or fruit gardens of Malabar region of Kerala (Anon., 1954). In both South Kanara and Malabar regions, it is now proposed to grow 'Andrews', a Sea Island (*barbadense*) cotton (Sethi, 1956).

Bourbon cotton was the first *hirsutum* to be tried out in the then Bombay Presidency (i.e., in 1797 A.D.) as well (Mackenna, 1918). After 1810, it was particularly tried out in the Island of Salsette, Kaira district (Gujerat) and Ratnagiri district, at the instance of the British East India Company. Although stray Bourbon plants got naturalised on the Island of Salsette, every attempt to cultivate the species there failed (Gammie, 1908). Pro-

duce from Kaira district alone was of the desired quality but was obtained at a loss of about 28 per cent. Other commercial varieties of *hirsutum*, New Orleans and Georgian Upland, were introduced into Bombay Presidency from 1828 onwards (Mackenna, *loc. cit.*). Yields from these cottons were small and even the staple turned out to be shorter (Gammie, 1908). On meeting with a series of failures in growing the New World cotton in India, the East India Company resolved in 1838 to secure the services of experienced American planters for the purpose of training local cultivators in the best methods of growing the New World cotton. The foreign planters too got convinced that these cottons, especially New Orleans cotton, were not suitable for cultivation in Gujerat, western India. In spite of repeated failures, the East India Company persisted in its efforts to grow the New World cotton in India, and by 1842 Georgian Upland and New Orleans varieties got successfully naturalised in a limited area of Upper Karnatak (Dharwar tract of the present Mysore State). This cotton came to be known by the name of Dharwar-American.

In the period 1842-1906, different commercial varieties of the New World cotton were tried out in Madras (Anon., 1954), Bengal (Mahta, 1947), Khandesh districts of Bombay (Khadilkar, 1947b; Prayag, 1927), Sind-now in Pakistan-(Main, 1907) and other parts of the country for varying lengths of time. Georgian Upland variety of *hirsutum*, introduced in Malwa and Nimar tracts of present Madhya Pradesh State in 1842 (Simlote, 1956), in the Punjab in 1850 and in Vidarbha tract of present Bombay State in 1866, got mixed with the local cotton of these and adjoining areas. The *hirsutum* components of the cottons of Vidarbha tract (present Bombay State), Nimar tract (present Madhya Pradesh) and Rajasthan area were known by the names of Buri, Malan and Mewar Upland, respectively. In the Punjab, in the opening years of the 20th century, Messrs. Mela Ram and Sons of Lahore collected seeds from stray *hirsutum* plants and laid the foundation of the Punjab-American cottons (Afzal, 1946b).

A more or less contemporary private firm, Harvey and Co. of Virudunagar, is credited with the spread of another *hirsutum* race *latifolium* cotton, Cambodia, in Madras State. The variety takes its name after the place Cambodia in Indo-China from where its seed cotton was originally received as a mixture in bales of lint imported in the then French Settlement in India, Pondicherry. During 1906, its seeds were procured from the president of the Chamber of Commerce, Pondicherry, by Mr. Benson for trial in Madras State. It failed as an unirrigated crop but in 1907, its high potentiality for yield was discovered by Mr. Steel of the aforementioned Harvey and Co. According to Lewton (1925), this Cambodia cotton can be traced to direct introductions by the Spaniards from Mexico to the Philippines. Thus, unlike Uplands, they never passed through the U. S. Cotton Belt and as such were never selected for long day fruiting. It is probably for this reason

that they have failed to compete with Uplands in northern India (Hutchinson, 1951).

In Uttar Pradesh, the establishment of *hirsutum* cotton was delayed mainly due to limited water supply at the time of its sowing in April-May when a sugarcane crop received prior attention. With the augmentation of irrigation facilities by 1936, attempts to grow *hirsutum* cotton in Uttar Pradesh were renewed and a variety, originally acclimatized in Persia, yielded a suitable strain for the tract. It is known as the Perso-American cotton and belongs to Upland stock. It was originally introduced into Uttar Pradesh several years ago by Dr. Leake (Sethi and Sant, 1941). Lately, varieties of Punjab-American cotton belonging to Upland stock have become popular in Uttar Pradesh in place of Perso-American cottons.

Thus, two different annual *hirsutum* race *latifolium* cottons got a firm foot hold in India; Uplands from the United States Cotton Belt received by the western route and Cambodias from Mexico received by the eastern route. From their first places of acclimatisation within the country, they found their way to the other regions of cotton cultivation in the country. Dharwar-American was introduced in lower Karnatak (Mysore State) in 1845 and through mass selection, local Dodahatti cotton originated (Dorasami and Srinivasa Iyengar, 1948; Ramiah, 1948). Cambodia was introduced from Madras into Malwa (Dhar) in 1912 as a money crop substitute for poppy whose cultivation was legally reduced to the minimum. It soon got mixed up with the pre-existing mixture of the tract comprising *arboreum* and Upland cottons (Simlote, 1956). Cambodia cotton also appears to have entered Kathiawar tract (Bombay State) several years ago (Anon., 1956a). It soon got mixed with the local **Hebacea** cottons and the mixture is known as Kodayo. In recent years, Punjab-American cotton varieties of Upland stock have been recommended for cultivation as summer crops on the rice fallows of South India (Kalyanaraman and Rangaswami, 1955), especially in the Cauveri delta (Balasubrahmanyan, 1952a) and the deltas of Krishna and Godavari (Seshadri Ayyangar and Padaki, 1956).

Until recently the efforts made by several institutions and agents to acclimatize the *barbadense* group of cotton in various parts of India ended in total failure. In this case also the British East India Company was the pioneer in introducing Sea Island cotton in 1831 in South India (Anon., 1954), Egyptian cotton in 1836 in western India (Mackenna, 1818) and both Egyptian and Sea Island cottons in 1846 in Sind, Pakistan (Main, 1907). One of the major attempts at large scale cultivation of these *barbadense* cottons in Sind was made after the introduction of perennial irrigation system in 1932 under the Lloyd Barrage and Canal systems. The problem was tackled scientifically. Two varieties of Egyptian and one of Sea Island had been introduced for trial at Sakrand in 1926 and from these types three pure selections were made. These were spread over 12,000 acres by 1937-38

(Sankaran, 1947). Subsequently, however, their cultivation declined because of low yields. Dastur's (1949) physiological investigations have revealed that these types flowered and fruited at a time when their photosynthetic activity was very low and hence their yields were poor.

Barbadense cotton was first introduced in Malabar (now in Kerala) and South Kanara (now in Mysore) by 1930. The experiments made by Agriculture Department Stations to grow this cotton as a rainfed, mixed and catch crop on rice fields failed. A private grower of South Kanara, however, continued to grow successfully, with adequate care, Sea Island cotton in his homestead for 15 years (Kalyanaraman, Ramaswami and Vaman Bhatt, 1955). Latest systematic acclimatisation experiments of Kalyanraman *et al.* (1955) have revealed that Sea Island cotton can be successfully grown as an unirrigated pure crop in the above-mentioned region whose eco-climate discloses some marked similarity with that of the West Indies. Variety 'Andrews' has now been adopted for cultivation in this region (Sethi, 1956) (Plate XII-b).

On the basis of climatic parallelism with Egypt, southern irrigated zone of Mysore was considered suitable for introduction of Egyptian cotton. Preliminary experiments of Dorasami and Srinivasa Iyengar (1951) have shown that although this cotton puts up a good vegetative growth its yield is still low.

Jooloor and Sahasrabuddhe (1953) have attempted acclimatising Egyptian cotton (*barbadense*), Karnak, by grafting it on to stocks of *arboreum* (Jarila). The grafted plants showed perennial habit and were not affected by jassids for four years ; they, therefore, could be used for cultivation in areas where perennial cottons can be grown.

Improvement of Gossypium hirsutum Cotton

In India, the *hirsutum* cottons now form about 25 per cent. of the total cotton output. They are grown under conditions of assured rainfall or under irrigation. They are grown as summer crops in areas spread over the entire Indian territory ; in the areas of the Deccan receiving winter rains from the north-east monsoons; they are also grown as winter season crops. Sowing time of summer crops varies in different States: January to April in Madras and Mysore States, mid-April to June-end in the northern riverine plains and at about the break of the south-west monsoons by June in the rest of the country. Winter *hirsutums* are sown from August to October. Duration of the winter and summer *hirsutum* race *latifolium* crops is about five to seven months.

Madras State. Cambodia cotton of Madras State is cultivated under irrigation or rainfed conditions. The rainfed crop is grown in winter (Sept.-Oct. to Mar.-Apr.) under precipitation received from the north-

eastern monsoons whereas the irrigated crop is taken in winter or summer (Feb.-Mar. to Aug.-Sept.). Work on the improvement of this cotton has been reviewed in Memoirs of the Department of Agriculture (1954) and by Kalyanaraman (1954, 1955).

Pure line selection work was begun on acclimatised Cambodia cottons at Coimbatore in 1918 and a strain, Cambodia Coimbatore 2, suitable for cultivation in winter on red loamy to light black soils under irrigated or rainfed conditions was evolved. By 1949 it covered nearly 75 per cent. of the total Cambodia region, though it possessed two defects : late maturity (*c.* 7 months after sowing), and susceptibility to stem weevil.

With a view to improving staple length of Madras Cambodias, a very large number of *hirsutum* varieties were collected from America, Africa and Russia and used in hybridisation programme executed at Coimbatore in winter and at Srivilliputur in summer, since 1932. From crosses of Coimbatore 2 with two Uganda (Eastern Africa) cottons, U.4/4 and A.12, strains, Coimbatore 3 and Coimbatore 4, respectively, were evolved. Strain 4463 was also evolved from a similar cross of Coimbatore 2 with a *hirsutum* type from Uganda. These three strains registered improvement over Coimbatore 2 in staple length (1/8″ more) and growth period (1 month less) of the crop. Coimbatore *tehsil* preferred 4463 in place of Coimbatore 2 for the intensive cropping of sorghum-cotton practiced in the region. Coimbatore 3 gained popularity in Salem district, both as an irrigated and as a rainfed crop, to the exclusion of other indigenous types. The release of Cambodia Coimbatore 4 marked a milestone in the progress of cotton improvement in Madras on account of its spread as an off-seasonal crop in tank irrigated rice lands of the southern districts in summer months. The practice of growing *hirsutum* in summer also spread to the coastal areas of South Arcot district characterised by high water table and assured water supply. All the three new strains could be classed as being equal to some of the imported types in staple length. The older strain, Coimbatore 2, still held the field in rest of the late planted (winter) tracts under irrigation.

Thus by 1943, it was realised that Madras State was studded with a multiplicity of varieties of *hirsutum*, each recommended for cultivation in district ecological zones. Moreover, they proved susceptible to bacterial blight. A reselection type, Madras Cambodia Uganda 1, obtained from Coimbatore 4, proved tolerant to blackarm and suitable for the whole of the wide range of environmental conditions covering the red soil tract, adopting different crop sequences and planting dates. Its seed cotton yield and ginning outturn were at par with those of the local types. It required one irrigation less in irrigated tracts and evaded drought by early maturity in rainfed tracts. It was thus a cosmopolitan strain capable of unifying the winter and summer areas of cotton cultivation. It had a consistent record in winter and summer seasons as well as under irrigated and rainfed conditions. In addition, it

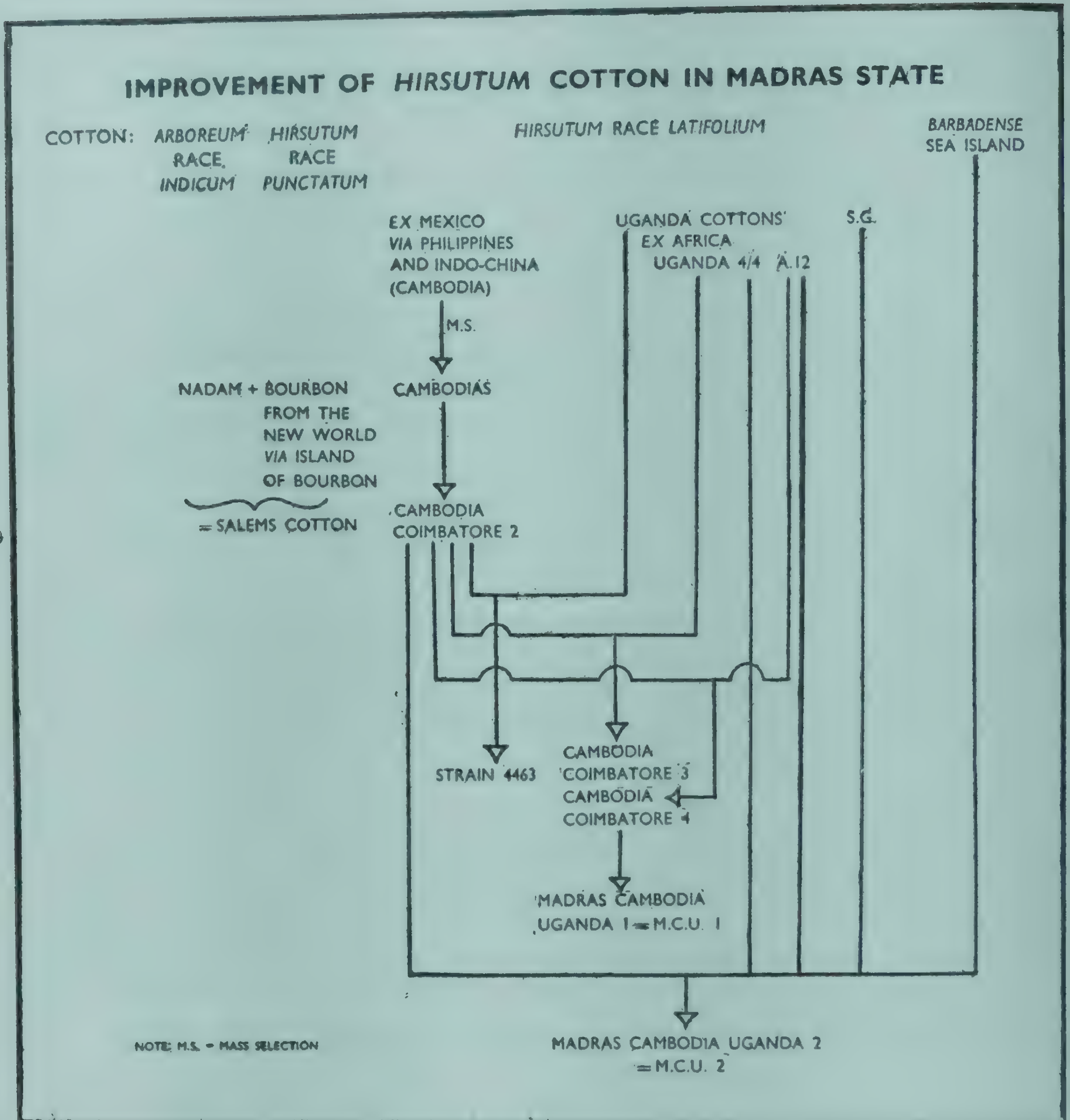


Fig. 28. Improvement of *hirsutum* Cotton in Madras State

was free from leaf curl disease and was resistant to jassids at Coimbatore (Plate VIII-a).

With the object of evolving strains of *hirsutum* with a staple length of 1-1/16" and ginning percentage up to 38, suited to winter cropping under irrigation, interspecific hybridisation work was begun in Madras State in 1949. A batch of 27 selections in advanced stages from the multiple interspecific hybrids was tested in co-ordinated yield trials on a common pattern layout at Coimbatore, Awanashi and Tiruchengode as a winter crop. They were also tested at Srivilluputur as a summer crop to find out whether they prove to be cosmopolitan or not. Strain 9030, besides possessing fibre and spinning properties like those of winter crop of Madras Cambodia Uganda 1, recorded an increase in lint yield of the magnitude of eight per cent. Its multiplication and distribution in the winter sown irrigated region at present occupied by M.C.U.1 awaited the results of the final district trials (Kalyanaraman, 1955).

The evolution of early maturing Cambodia Co.4 and its reselection M.C.U.1 gave a considerable fillip to the cultivation of *hirsutum* under irrigation during summer in Madras State. It was soon noticed that cotton grown under these conditions possessed longer staple, better fineness and superior quality as compared with the improved varieties grown in winter. This special feature was sought to be utilised in the breeding of long staple cottons for the summer tract. Work was begun in 1947 at Palur but on experiencing defective anthesis (due to contabescence of anthers) and defective seed formation under high temperature and low humidity conditions, obtained at the station, the venue of research work was shifted to Srivilluputur in 1949. A comprehensive programme of backcrossing and multiple crossing involving Co.2 and Uganda strains of *hirsutum* and the superfine cotton, Sea Island (*barbadense*) led to the isolation of the type Madras Cambodia Uganda 2 (Jagannatha Rao, Marar and Santhanam, 1953). It proved earlier than M.C.U.1 by a fortnight and possessed superior fibre properties (Fig. 28 and Plate VIII-b).

Encouraged by the experience of growing cotton on rice lands in short fallow periods during summer, experiments on utilising similar fallow periods of the rice lands in the old Cauvery Delta of Tanjore district, coastal area of South Arcot district and certain areas of Coimbatore district, were started in 1950 at Aduthurai, Palur and Coimbatore, respectively (Kalyanaraman and Rangaswami, 1955). Early maturing Upland types proved suitable for these areas: Coker from the U.S.A. for Tanjore district, and 216F and 23F from the Punjab for Coimbatore and South Arcot districts, respectively. In the absence of natural variability in the Punjab varieties of Upland cotton and in view of their specific defects such as shorter staple, smaller bolls and susceptibility to red leaf, hybridisation work making use of exotic types such as Coker and Sealand, has been undertaken.

Cambodia Co. 2 and M.C.U.1 made a certain amount of headway in the rainfed winter cotton areas of Madras State but bulk of the cotton remained a mixture of degenerated forms of some of the Cambodia strains. With a view to evolving a hardy and better adapted strain for this tract acclimatisation and hybridisation experiments were begun in 1950 at Periakulam. Acclimatisation of *hirsutum* material from Central America, Brazil and East Africa, proved a failure since most of the types succumbed to red leaf disease and jassids and were late in maturity. *Gossypium hirsutum* types from the other parts of India also proved to be unsuitable (Kalyanaraman, Neelakantan and Krishnan, 1955). Some hybrid material produced at Coimbatore proved promising (Kalyanaraman, 1955).

Mysore State. Both Cambodias and Uplands are grown in this State. Improvement of Dharwar-American (Upland) cotton was started with the opening of the farm at Dharwar in 1904 and at Gadag in 1908 (Kulkarni and Khadilkar, 1929). Pure line selection led to the isolation of Gadag 1 in 1914. It was superior to local *hirsutum* cotton in yield and other economic characters but in some seasons it suffered severely from red leaf blight. To eliminate this defect it was crossed with Cambodia Co. 2, a *hirsutum* type from Madras State, resistant to red leaf blight. Pedigree breeding led to the isolation of Laxmi from this hybrid material (Tippannavar and Patil, 1952). Laxmi is superior to the former type in ginning value as well as fibre properties. In addition, it is early maturing and resistant to red leaf. On the initiative of the cultivators who were lured by the cash value, Laxmi was likely to fetch for them, the type spread out indiscriminately into areas other than Dharwar-American tract comprising Gadag and Ron *talukas* in Mysore State. Within this State it occupied Raichur, Bellary and Chitaldrug (northern part only) districts, and partly encroached upon the Kumpta (*herbaceum*) areas. In the neighbouring Andhra Pradesh it infiltrated into the Westerns (*herbaceum*) and Mungari (early sown *arboreum*) cotton regions of western Rayalaseema tract. The type had been evolved for cultivation on medium black soil as a rainfed, *hingari* (late sown) season crop in Dharwar-American tract; it proved to be a failure in other areas. Laxmi is unsuitable for cultivation in the *mungari* (early sown) season on lighter soils and under irrigation.

Experiments were conducted under rainfed conditions at Hagari and under irrigation provided by the Tungabhadra Project at Siruguppa to test the suitability of *hirsutum* cottons in Bellary district (Mysore State). A large number of *hirsutum* types from within the country and from abroad, e.g., Cambodias from Madras, Uplands from Gadag, Dharwar and Parbhani (India), U.S.A. and Uganda (Africa) and *hirsutum-arboreum* and *hirsutum-herbaceum* hybrid derivatives from Surat (India) were tried out during the period 1937-43. When grown as a summer crop (*kharif*), the *hirsutums* matured late and suffered from red leaf blight. When grown as a winter

crop (*rabi*), under irrigated or rainfed conditions, incidence of blackarm and jassids was a regular feature. Intensive breeding work was undertaken to evolve jassid and blackarm-resistant types (Jagannatha Rao, Raghavan and Appa Rao, 1953). Mysore-American 2 was found to be fairly resistant to jassids. Culture 1821, a reselection from Surat tetraploid, B.C. 68, proved greatly jassid-resistant and another culture, 2196-4, derived from a complex cross showed remarkable resistance to blackarm. These cultures are being used in hybridisation experiments for obtaining suitable high yielding and disease and pest-resistant biotypes.

The problems of *hirsutum* cotton cultivation in the Tungabhadra Project area and the lines along which they are being tackled have been summarised by Appa Rao (1955). The problems are : bad opening of bolls, immaturity of fibres, damage by insect pest—thrips in particular—and by blackarm disease and difficulties in acclimatisation of long linted cottons. At Siruguppa, the percentage of immature locks comprising bad seed cotton was 13·3 in the variety, Mysore-American 2. It was evident that yield of cotton could be stepped up by decreasing the percentage of immature locks. Breeding work in this direction led to the isolation of culture 2204 from a Surat backcross progeny which possessed only 2·8 per cent. immature locks. Regarding the problem of immaturity of locks, Harland (1955a) has remarked that smaller boll size may be selected as the chances of big bolls getting filled up with cotton under stringent conditions are likely to be lesser comparatively. He emphasized the importance of work on determining the optimum boll size in the tract. Mysore-American 2 and Hyderabad-American 11, both showed a high degree of fibre immaturity at this centre but two types (2955 and 2963) evolved from the cross of Gadag 1 with Perso-American cotton have given encouraging performance in regard to greater fibre maturity (61% to 75%). Mysore-American 2 and the blackarm-resistant strain 2196 showed resistance to the attack of thrips. The type 14 x 6 *ex* Greece proved outstanding from the point of view of resistance to thrips.

In rainfed areas of Raichur district, Laxmi succumbed to root rot and jassid and aphid attack (Jagannatha Rao and Venkatachary, 1955; Bederker, 1955d). Some jassid-resistant strains have been isolated by selection from Laxmi (Bederker, *loc. cit.*).

The work on the improvement of *hirsutum* cotton in the lower Karnatak is reviewed by Sreenivasa Ayyangar (Srinivasa Iyengar, 1941, 1956), Dorasami (1947) and Dorasami and Sreenivasa Ayyangar (1948). Cotton breeding work started in the region in 1917 at Babbur. Mysore-American 2, evolved in 1928 from the cross of local *hirsutum* cotton, Dharwar-American (also known as Dodahatti local) with a tree cotton (*G. barbadense*), far excelled the local *hirsutum* cotton in yield, ginning outturn (30%), staple length and spinnability. It resisted the scourge of red leaf blight to a very great extent as compared to the local. It was resistant to jassids also. It proved to be a cosmopolitan

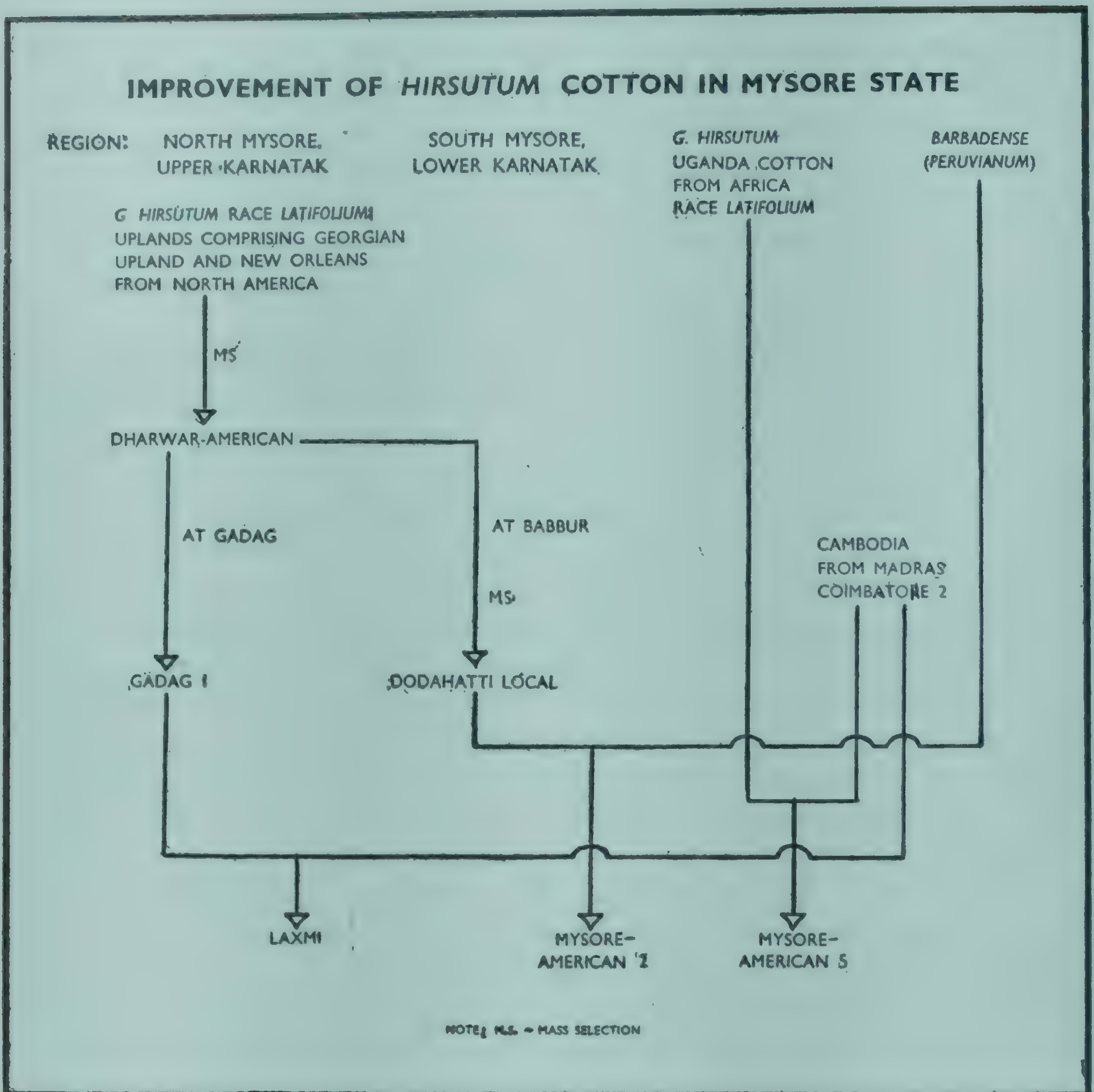


Fig. 29. Improvement of *hirsutum* Cotton in Mysore State

strain suited for cultivation both in red and black soil tracts. Small boll size and bad boll opening are the two defects of this type, Mysore-American 2. Further work on improvement of *hirsutum* cotton was not taken up until 1936 when the Irwin Canal Project opened up the possibilities of cultivating the much needed quality cotton, *hirsutum*, under irrigation. Cambodia Co. 2 obtained from Madras State and various other *hirsutums* received from other parts of India were used in hybridisation programme. As a result of initial trials conducted at research stations, one strain Mysore-American 5 was found to be the best. It is evolved from the cross of Cambodia Co. 2 with the African *hirsutum*, Uganda Upland. It is fairly resistant to red leaf blight and jassids. Though primarily bred for red soils, M.A.5 has successfully replaced Nadam, perennial *arboreum* cotton of the black soil tract also (Fig. 29 and Plate XXIX-b).

With a view to further improving the staple length and spinning quality of M A.5, it was crossed with a number of long stapled, high spinning Uplands from the U.S.A., (e.g., Tidewater) in 1948. Selection in hybrid progenies has resulted in the isolation of a few new strains, which while maintaining the yield and ginning outturn of M.A.5 possess longer staple length associated with superior spinning value. These are being tried out together with Mysore-American 5 and Madras Cambodia Uganda 1 from Madras State in the various zones (Srinivasa Iyengar, 1956).

Taking into consideration the remarkable success of the early maturing Upland (*hirsutum*) varieties of cotton from the Punjab in short duration fallows of the rice lands of Madras State, similar trials were conducted at Hiriyur (Vanivilasa Sagar area) and Mandya (Visveswariah Canal area). Variety H.14 has given satisfactory results at both the stations but at Hiriyur alone, the optimum period of cotton sowing correctly fits into the cotton-paddy rotation. Selections from the Punjab *hirsutum* types and hybrid progenies obtained by crossing them with local *hirsutum* material are under inspection with a view to evolving a strain superior to H.14 for being sown as a summer crop in rice lands (Srinivasa Iyengar, 1956).

Andhra Pradesh. In Andhra Pradesh *hirsutum* cottons are grown in Rayalaseema tract in the south and in sub-montanous Adilabad region in the north. Both Upland and Cambodia types are under cultivation.

Venkoba Rao, Seshadri Ayyangar and Jagannatha Rao (1955b) have reported on trials of *hirsutum* types, Dharwar-American, Hyderabad-American 11, Mysore-American 2 and Laxmi at Nandyal and other district centres of Rayalaseema tract under rainfed conditions. The results were in favour of Laxmi, the type which caught the imagination of local farmers. Work for breeding a blackarm and jassid-resistant *hirsutum* type had, however, to be continued since Laxmi did not show resistance to either of these hazards. A selection, 327, combines superior values for yield and lint quality characters. Its resistance to disease and pest hazards is being tested. Hybrids

of the disease and pest-resistant cultures 1821 and 2196 with the quality strains such as Sudan 60, Laxmi, Dharwar-American 2, B.C.134 x C.W. and 170-Co.2 made at Siruguppa (Mysore State), are also being tried out at Nandyal.

Cultivation of cotton was tried out on the large areas existing as rice fallows in the single cropped wet lands of the deltas of Godavari and Krishna rivers in Andhra Pradesh at Maruteru, Samalkot and Buchireddipalem. Short duration *hirsutum* types from the Punjab, 216F and 23F, proved most promising when sown during November in the stubbles of harvested paddy (Seshadri Ayyangar and Padaki, 1956).

The original *hirsutum* cotton in Adilabad region appeared to be remnant of Buri (Upland) cotton which had made its way into this area from the adjoining Vidarbha area of Bombay State. Selection work carried out at Parbhani (Bombay State), led to the isolation of the type, Parbhani-American 1, which proved suitable for the highland areas of Adilabad district receiving assured rainfall (Anon., 1956a).

Bombay State. *Gossypium hirsutum* is grown in limited areas of Vidarbha-Aurangabad tract, Poona tract and Gujerat tract of the State either under irrigation or under rainfed conditions.

Vidarbha Tract : The acclimatised *hirsutum* cotton comprised both Cambodias and Uplands ; the breeding work done on this cotton in the area has been summarised by Bhatt and Shrivastava (1956). The cotton received the name Buri due to the extreme fuzziness of its seed. Owing to its resistance to the disease *dahiya* caused by *Ramularia areola*, it is being preferred over the *arboreum* in certain regions (Bhatt and Shrivastava, 1956; Labhshetwar, Paranjpe and Bhatt, 1956). Intensive selection for staple and yield at Akola and Nagpur led to the isolation of Buri 107 which possessed fine lint of 15/16" staple capable of spinning to 40 H.S.W.C., besides giving *c.* 28 per cent. ginning. It was resistant to wilt and frost. Reselection in Buri 107 led to the isolation of the type Buri 0394 which has whitish soft lint of good strength and *c.* 15/16" staple. Buri 0296-7, a reselection from Buri 0382 obtained at Achalpur, has registered further improvement over Buri 0394 in yield and ginning (Plate IX-b).

With the increase in irrigation facilities for *hirsutum* cotton in the region, the hazards caused by blackarm disease and jassids are assuming alarming proportions. With a view to meeting the situation, a large collection including several *hirsutum* types from other regions of the country as well, is being screened at Achalpur against these hazards under conditions of artificial epiphytosis. Promising strains have been bred out both through reselection and through hybridisation of Buri 0394 with types obtained from Surat and Indore (Bhatt and Shrivastava, 1956).

Aurangabad Tract : Parbhani-American 1, a selection from locally acclimatised *hirsutum* at Parbhani, was released for cultivation in the sub-

montanous region of Aurangabad tract (Plate XXX-a). (Wealth of India, Unpubl†. see note to Table 36).

Gujerat Tract: Series of attempts made during the 19th century to introduce *hirsutum* cottons in Gujerat met with failure. This led to the desire for combining the fibre qualities of *hirsutum* cotton with the general adaptability of the Indian cottons, *arboreum* and *herbaceum*. The necessary interspecific hybridisation experiments were started at Surat with the onset of the second quarter of the present century (Desai, 1927). Several types have thus so far been isolated and are collectively referred to as Indo-American types. The economically important types are 170-Co.2 (Patel and Patel, 1954) and 134-Co.2-M (Bhat and Patel, 1955). The former type was derived from the cross *hirsutum* (Dharwar-American 2-6-5) x *arboreum* (Gaorani 6) made in 1936. The F_1 hybrid was being perpetuated as a ratoon plant and also as a graft. All the clones were self-sterile but on one of them a solitary tiny boll developed in 1940. It gave only four viable seeds. One of the plants raised proved to be tetraploid. It was presumed to have originated as a result of backcrossing of the F_1 hybrid to *hirsutum* and, therefore, was termed as 'Backcross 170.' This 'Backcross 170' plant was further crossed to Cambodia Co.2 (*hirsutum*) and by continuous selection in the subsequent progenies the type 170-Co.2 was obtained. Its staple length is nearly 1-1/8". The type 134-Co.2-M is evolved from the progenies of the third backcross of *hirsutum* x *herbaceum* hybrid to *hirsutum* made in 1941-42. First backcross of the hybrid *hirsutum* (Dharwar-American 2-6-5) x *herbaceum* (1027A L. F.) was made to the female parent. Later two backcrosses were to the *hirsutum* varieties, Cambodia Co.2 and Meade. The strain 134-Co.2-M proved inferior to 170-Co.2 at Surat (South Gujerat) in yield and ginning percentage but in the light and *goradu* soils of middle and North Gujerat the former showed all round superiority over the latter (Bhat and Patel, 1955). The mean fibre length of 134-Co.2-M even under bulk sowings is about 1·14". Both the Indo-American types, 170-Co.2 and 134-Co.2-M, are under large scale cultivation in Gujerat as irrigated as well as rainfed crops (Plates VII-a,b and XXX-b).

The above mentioned Indo-American types do not have a root system as deep as that of the types belonging to indigenous species. They, therefore, suffer from thrip attack. They also show boll shedding in droughty periods caused either by deficit rainfal or by a prolonged break in the monsoons. Some perennial *hirsutums*, well adapted to Surat conditions are being used in hybridisation programmes for evolving deep rooted annual forms of economically superior *hirsutum* types for this tract (Pandya and Patel, 1956).

Poona Tract : The Indo-American type 170-Co.2 evolved at Surat was tried out, along with other types of *hirsutum*, at Kopargaon and Padegaon under irrigation. Since its performance was encouraging it is being distributed in the region.

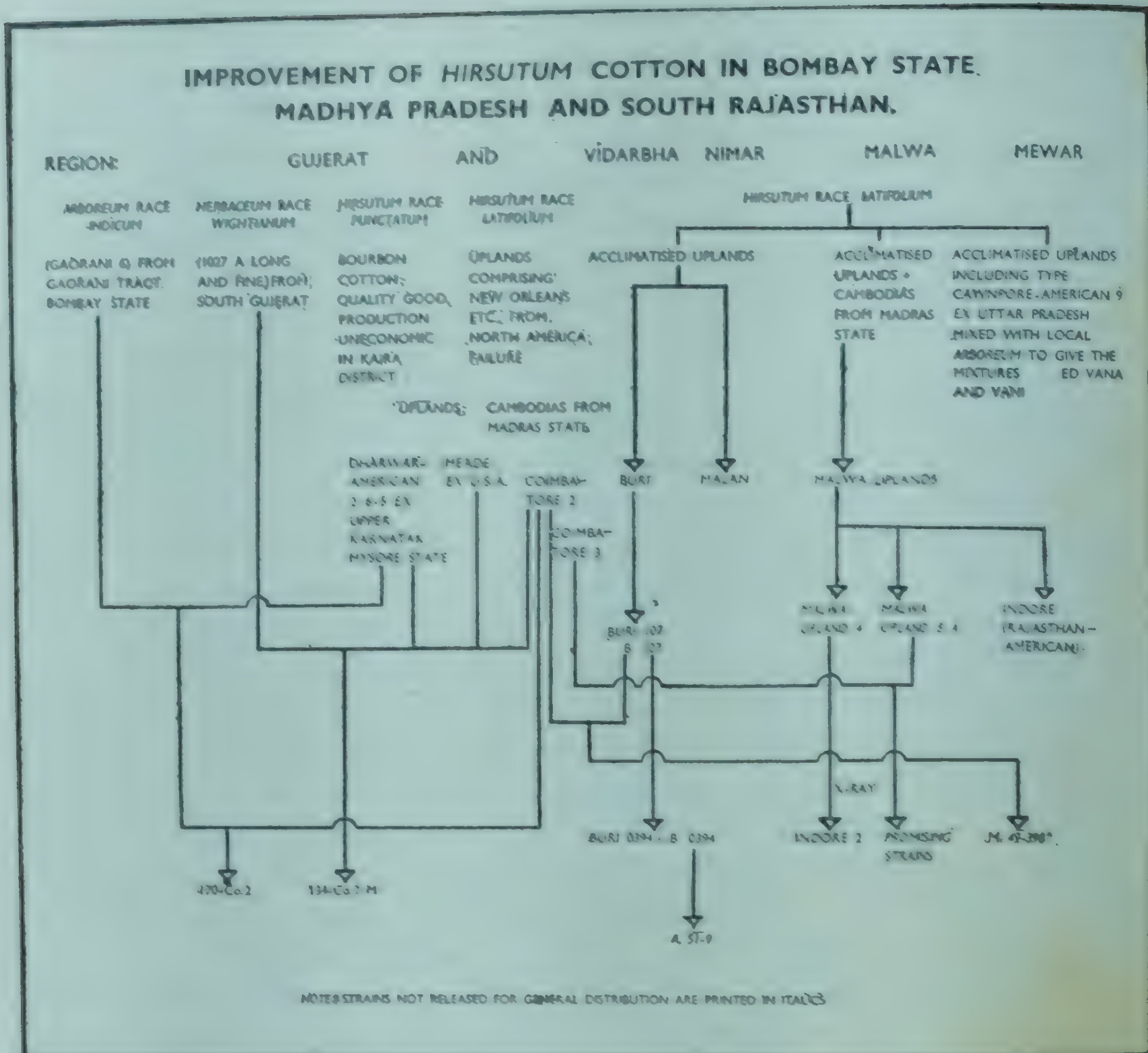
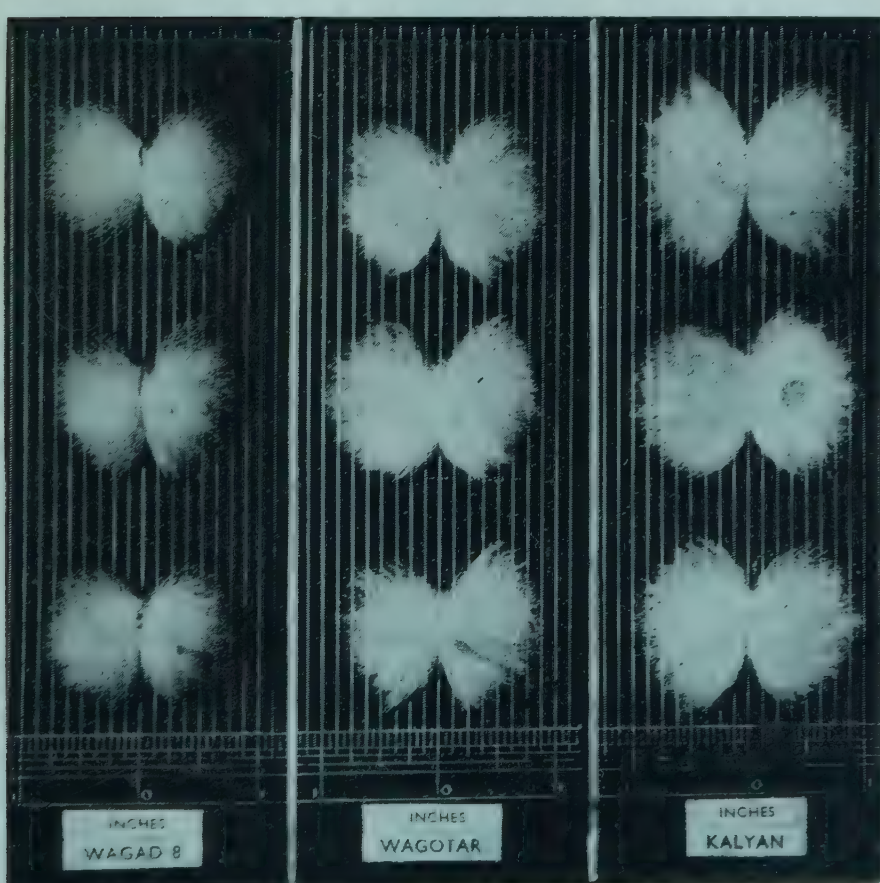


Fig. 30. Improvement of *hirsutum* Cotton in Bombay, Madhya Pradesh and South Rajasthan

a. Staple Length of Broach Cottons



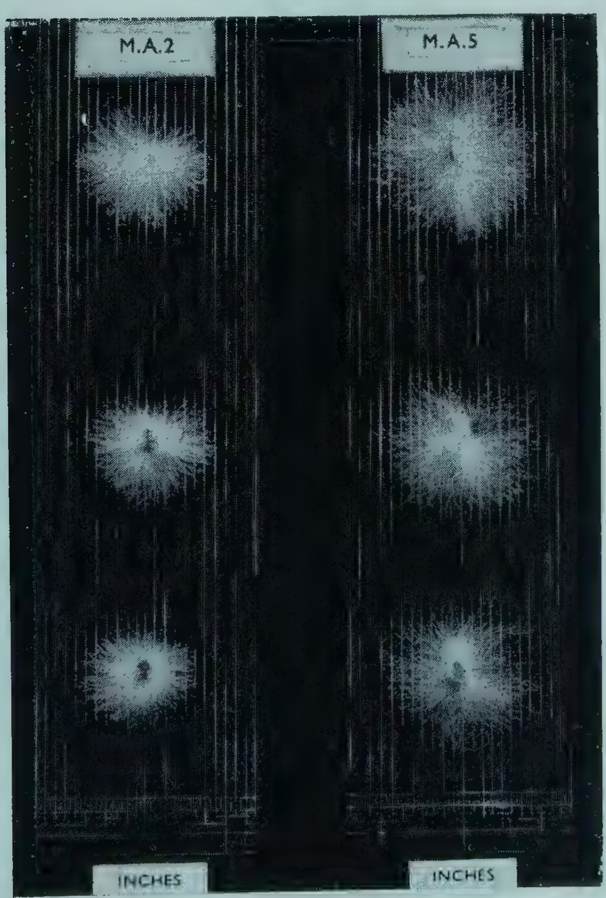
b. Staple Length of Wagad Cottons

PLATE XXVIII

a. Staple Length of Karnatak Cottons

b. Staple Length of Mysore Desi Cottons

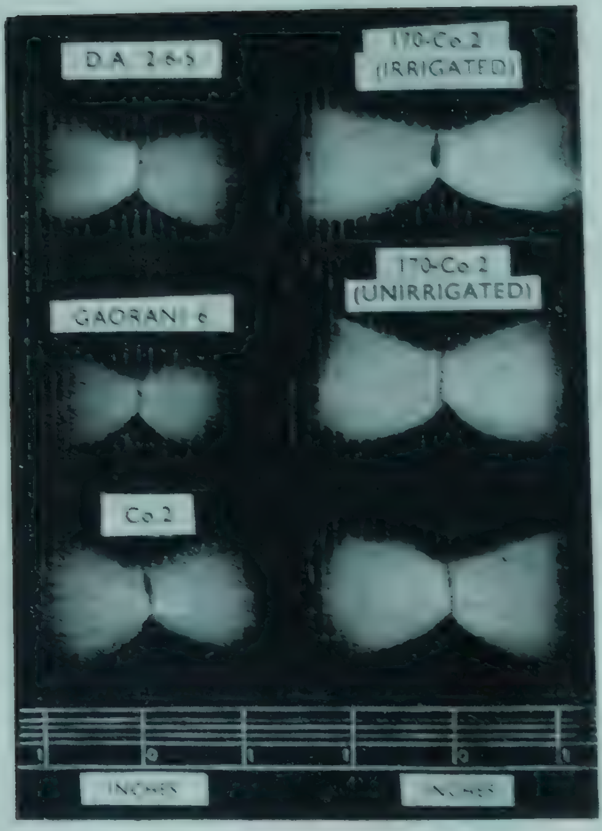
a. *Gossypium hirsutum* race *marie-galante*



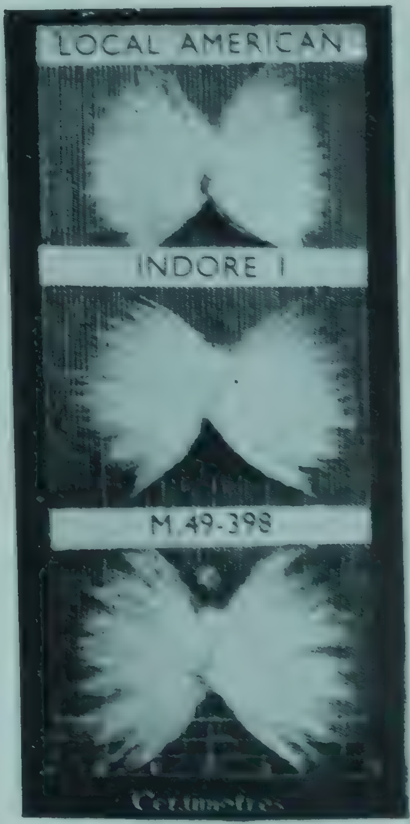
b. Staple Length of Mysore American Cottons

PLATE XXX

a. Parbhani-American 1



b. Staple Length of Indo-American Cottons



c. Staple Length of Rajasthan Cottons

Madhya Pradesh. *Gossypium hirsutum* cotton acclimatised in Nimar tract of the State is of Upland stock and is locally called *Malan* (Simlote, 1956). During the past two decades or so, *hirsutum* has displaced nearly 50 per cent. of the *arboreum* cotton in the tract. Buri types evolved at Nagpur and Akola (see under Vidarbha tract of Bombay State) were taken up for cultivation. Work on reselection or hybridisation in *hirsutum* types Buri (Bombay State) and Laxmi (Mysore State) is in progress at Khargone in the area ; one of the promising strains evolved is A.51-9 (Kocharekar, 1955).

In the Malwa tract of the State acclimatised *hirsutum* cotton is a mixture of both Upland and Cambodia stocks; the Upland component goes by the name of Malwa Upland (Simlote, 1956). Cultivation of *hirsutum* (Dhar Cambodia) cotton in the Malwa tract is restricted to Dhar district under rainfed conditions. Selection programme in the acclimatised material was carried out at Indore and two types, Malwa Upland 4 and Malwa Upland 8A, were isolated. When tried out against the local cotton in the *hirsutum* tract, neither of them proved to be superior (Gadkari, 1954; Simlote, 1956). Seeds of Malwa Upland 4 were treated with X-rays (Ramiah and Bholanath, 1946). One of the resulting progenies proved to be markedly improved; it was named as Indore 2 (Gadkari, 1954). This strain possessed a staple of 15/16" as against 27/32" of Dhar Cambodia. It was superior in yield, ginning value and spinning value. It was comparatively more resistant to jassids and red leaf blight. The locally evolved types are being used in hybridisation with other *hirsutums*, such as, Cambodia Co.3, Madras Cambodia Uganda 1, Laxmi and also those from East Africa. The work is in progress both at Indore and at Badnawar in Dhar district (Simlote, 1956) (Fig. 30).

Rajasthan. *Gossypium hirsutum* cotton is grown in southern Mewar tract of the State under irrigation from tanks and wells and in the northern Ganganagar Colony under canal irrigation. Original cotton of the Mewar tract belonged to *arboreum* race *bengalense* until Cawnpore-American 9, an Upland stock of *hirsutum* was introduced into the area from Uttar Pradesh in 1921 (Simlote, 1956). The mixed cotton in which *bengalense* predominated was known as Vani and that in which *hirsutum* predominated was known as Vana.

The type Indore 1 selected from Malwa Upland cotton at Indore (Madhya Pradesh) proved to be a better *hirsutum* for these light soil areas of southern Rajasthan. Local Upland was the earliest but suffered greatly due to leaf roll and red leaf diseases. Indore 1 was comparatively only a week late in maturity but suffered less from the diseases. Further breeding work is in progress at Udaipur where initial material from intervarietal hybridisation in *hirsutum* has been received from Indore. M.49-398, a type

obtained from the cross (Buri 107 x Cambodia Co.2), has given a good performance (Simlote, 1956) (Plate XXX-c).

The first settlers of the Ganganagar Colony were mostly from the Punjab. Both *arboreum* (Mollisoni) and *hirsutum* (289F/43) cottons were introduced by them from the Punjab (Simlote, 1956). At present 216F, the *hirsutum* of Hariana tract of the Punjab, is being grown in the area (Sethi and Dharmarajulu, 1957).

Uttar Pradesh. The earliest attempt to grow *hirsutum* cotton in the State was made at Cawnpore (now spelt Kanpur) from imported exotic types. Single plant selections resulted in the isolation of Cawnpore-American 9 cotton which was given out for distribution in Central Circle of the State. The acreage, however, dwindled on account of lack of sustained interest and irrigation facilities and unorganized marketing conditions (Anon., 1956a). At Cawnpore, a pure line selection of an Upland cotton introduced by Dr. Leake several years ago from Persia was being maintained. This variety named Perso-American was found suitable for cultivation in the Western Circle (Sethi and Sant, 1941; Anon., 1956a). At present the variety 216F from the Punjab is the most popular in Uttar Pradesh (Sethi and Dharmarajulu, 1957).

Punjab. Improvement work on *hirsutum* cotton in the Punjab has been reviewed by Negi (1956) and Negi and Aujla (1956). The breeding work was first begun at Lyallpur (now in Pakistan) in 1907. Two selections, 4F and 289F, made from acclimatised *hirsutum* cotton were released for distribution in 1914 and 1921, respectively. The Punjab Botanical Scheme came into operation in 1925. It was one of the earliest schemes of the Indian Central Cotton Committee and it stimulated intensive work on the improvement of *hirsutum* cotton. Work done under this scheme and a number of other schemes which later came into being as its off-shoots, resulted in the evolution of many improved strains in a quick succession. Amongst these were Labh Singh Selection (L.S.S.), 289F/43, 124F (Victory) and 199F (Sultani). The last two varieties were released for cultivation just before Independence. Hardly any of the improved strains of *hirsutum* were available, for growing in the part of the Punjab which came to the share of the Indian Union. The general notion was that *hirsutum* cotton is not suited for the Punjab State in India. Realizing the urgent necessity of making the country self-sufficient in her requirements of long staple cotton, breeding work was taken in hand in right earnest on a regional basis in the State. The first successful step taken was the purification of L.S.S. in Ferozpur district. The type 216F, evolved by selection from M.4 of Sind (Pakistan), was released for distribution in Hariana tract where it has almost displaced the *arboreum* cotton by now (Negi and Avtar Singh, 1956). An early maturing selection from L.S.S. is named 320F (Negi and Sehgal, 1957). Its lint quality is superior to that of the mother strain. 320F, therefore, is rapidly displacing

L.S.S. in the western part of the State. The strain H.14, a reselection from 216F, is a distinct improvement over the mother strain in yield, ginning, qualities of lint, earliness and resistance to jassids. It also is fast substituting 216F in the south-eastern part of the State (Sethi and Dharmarajulu, 1957). With the spread of these improved *hirsutum* types in the Punjab, the State is now contributing nearly 50 per cent. of the total *hirsutum* cotton production in the country (Plates X-a and XXIV).

An extensive programme of hybridisation is in progress at Abohar to evolve strains with mean fibre length over an inch (Negi and Aujla, 1956). A series of Long Lint (L.L.) strains have been tried out on culivators' fields. L.L.53 and L.L. 54 gave yields slightly more than that of the control variety, 320F of the area and possessed greater mean fibre length (1·11″ and 1·08″, respectively, as against 0·91″ in 320F). Pressley strength value was comparable to that of the variety, 320F. In full scale spinning tests they gave 8 to 10 counts more than 320F. Two other strains, L.L.55 and L.L.56, seemed to be most superior in spinning performance; they consistently spun over 50 H.S.W.C. All the four strains, L.L.53 to L.L.56 originated from the cross of L.S.S. with 45F. Even better strains have recently been isolated from the extensive hybrid material available at Abohar. A majority of the selected progenies possess mean fibre length of 1–1/8″ and above and at the same time possess ginning value greater than that of 320F. The rare combination of these two desirable features is the most redeeming feature of the selections. It is expected that when some of these strains are finally released for distribution and when additional irrigation facilities become available on completion of the Bhakra-Nangal Project, the State would occupy a front rank position amongst the cotton producing regions of the country (Fig. 31).

IMPROVEMENT IN INDIVIDUAL CHARACTERISTICS

Yield. The position in regard to the acre output of seed cotton from the early and recent *hirsutum* types is summarised in Table 45. Barring the type Mysore-American 5, all others seem to show improvement in their yielding capacity over the earlier *hirsutum* cottons of their respective areas.

Ginning Percentage. The *hirsutum* cottons in India show a narrower range (*c.* 28 to 38 per cent.) of ginning values as compared to the types belonging to the indigenous species (Table 50). Ginning percentage figures for some of the early and recent *hirsutum* cottons of the different States have been entered in Table 46. It will be seen that there is improvement in the ginning character of all the Indian *hirsutums*, excepting Uttar Pradesh types and summer grown types in Madras State. The types showing improved ginning have either been evolved by selection alone or have been isolated from hybrid progenies (Figs. 28 to 31).

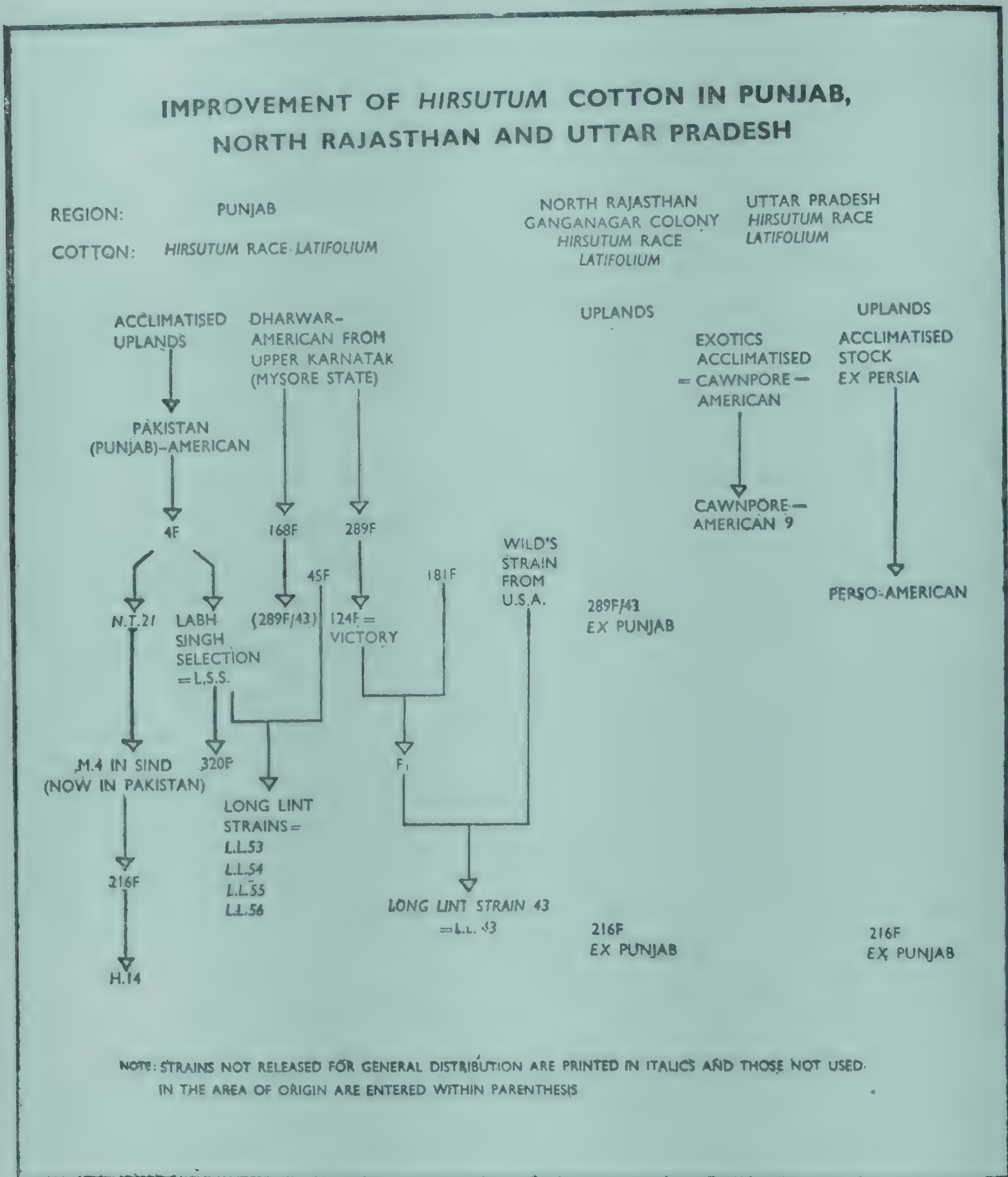


Fig. 31. Improvement of *hirsutum* Cotton in the Punjab, North Rajasthan and Uttar Pradesh

Fibre Length. Staple length and mean fibre length of all the *hirsutum* types under cultivation at present is better than that of the earlier types in their respective zones in the country (Tables 47 and 50).

The type 134-Co.2-M of Gujerat is one of the leading ones in length of its fibres; the mean fibre length is 1.14″. The parental types that gave rise to 134-Co.2-M are the indigenous *herbaceum* (1027 A L. F.), Upland (Dharwar-American) and Cambodia (Co.2) types and the exotic Upland (Meade). Madras Cambodia Uganda 2 grown in Madras State in the summer season also has a good fibre length (1.12″). Its parentage includes *barbadense* (Sea Island) and indigenous (Cambodia) as well as exotic (African) *hirsutum* cottons. The winter grown *hirsutum* type, M.C.U.1 of the same State also possesses good fibre length (0·986″); its immediate parent was evolved by hybridisation of indigenous (Cambodia) and exotic (African) *hirsutum*. In Mysore State, M.A.5 of similar parentage shows improvement in staple length over its predecessor M.A.2 evolved from the cross of Upland *hirsutum* with a perennial *barbadense* cotton. The other important *hirsutum* cotton of Mysore State is Laxmi (mean fibre length: 0·936″). It is of Upland-Cambodia hybrid descent. Improvement in fibre length of all the remaining prominent *hirsutums* of the different States in the country has been effected by selection from the local acclimatised material (Figs. 28 to 31).

Further improvement in mean fibre length (up to *c.* 1.20″) of *hirsutum* strains in the States of the Punjab (Negi and Aujla, 1956) and Madras (Iyengar and Santhanam, 1956) has recently been reported.

Fibre Weight. In general, the present *hirsutum* cottons of India are finer than those of the indigenous species (Tables 48 and 50). Barring the types, M.C.U.1 of Madras State and Indore 2 of Madhya Pradesh, all others show greater or lesser decrement in their fibre weight over the earlier cottons of their regions. Among winter *hirsutums* of Madras State, Co.3, possessed lighter fibres than those of the current type M.C.U.1. Madras Cambodia Uganda 2 grown in summer season in Madras State and possessing *barbadense* heritage shows the least fibre weight (0.105×10^{-6} oz.) per inch among all the cottons cultivated in India.

Spinning Capacity. A majority of the current *hirsutum* types possess much improved spinning values (Table 49). The leading high spinners are M.C.U.2 and M.C.U.1 of Madras State, Laxmi of Mysore State, H.14 and 320F of the Punjab and 134-Co.2-M and Buri 0394 of Bombay State. Spinning value of the type, 320F of the Punjab is nearly the same as that of its predecessor, L.S.S., despite its improvement over the latter in length and fineness of fibre (Table 49). The type 216F popular in the Punjab before the release of H.14 is being cultivated at present in Uttar Pradesh as it shows improvement over the early acclimatised *hirsutum* of this State in

TABLE 45. REPORTED ACRE YIELDS OF SEED COTTON FROM THE DIFFERENT *hirsutum* COTTONS GROWN ON EXPERIMENTAL FARMS (lb. per acre)

State	Early types	Value	Value	Later types	References
Madras	Winter Season:				
	Cambodia: Local	510	1037 (715 commercial)	*M.C.U.1.*	Kalyanaraman, 1954: *
	,, : Co. 2	100 *x* (707*)	124*x*	9030	Jagannatha Rao, Marar and Santhanam, 1953
	Summer Season: Co. 4	757	104*x*	*M.C.U.2*	,, ,,
Mysore	Upland: Dharwar-American	332	391	*Laxmi*	Kelkar and Kaiwar, 1954:*
	Mysore-American 2	990	813	*M.A.5*	Dorasami and Srinivasa Ayyangar, 1948
Andhra Pradesh and Bombay	Parbhani-American Local	250	250 to 456	*P.A. 1*	Anon., 1956a;*
Bombay	Buri 107	342	504 to 865	*B. 0394*	,,
Madhya Pradesh					
Malwa	Dhar Cambodia	423	478	*Indore 2*	Simlote, 1956
Nimar	*Buri 0394*	1001	1157	A.51-9	Kocharekar, 1955
Rajasthan (south)	Vana	931	990 to 1106	*Indore 1*	Simlote, 1956
Uttar Pradesh	Cawnpore-American	433	766	*216F*	Anon., 1956a
Punjab	Upland: *216F*	1207	1141 to 1267	*H.14*	Negi and Avtar Singh, 1956: Negi, 1956; Anon., 1956a
	,, : L.S.S	1051	1576	*320F*	*: Negi and Sehgal, 1957

Note: Where necessary the references for the character values entered in separate columns are separated by a colon.

Types printed in italics are those that are, at present, under cultivation. Those following them in their respective areas are the latest promising strains and those preceding them are the earlier types in the same region.

* Technological Reports on Standard Indian Cottons, Indian Central Cotton Committee, Bombay.

TABLE 46. GINNING PERCENTAGE IN THE DIFFERENT *hirsutum* COTTONS

State	Early types	Value	Value	Later types	References
Madras	Winter Season:				
	Cambodia: Local	33	36 to 38	*M.C.U.1*	Kalyanaraman, 1954: *
	Summer Season:				
	Cambodia: Co. 2	37	33	*M.C.U.2*	Jagannatha Rao, Marar and Santhanam, 1953
Mysore	Upland: Dharwar-American	28	35 to 37	*Laxmi*	Kelkar and Kaiwar, 1954:*
	Mysore-American 2	30	35	*M.A. 5*	Dorasami and Srinivasa Ayyangar, 1948; Anon., 1956a
Andhra Pradesh and Bombay	Parbhani-American Local	32	*c.* 30 to 33	*P. A. 1*	Anon., 1956a;*
Bombay	Buri 107	28	32 to 34	*B. 0394*	,,
			38·5	*170-Co.2*	Bhat and Patel, 1955
Madhya Pradesh					
Malwa	Dhar Cambodia	30·6	32·8	*Indore 2*	Simlote, 1956
Nimar	*Buri 0394*	31·9	37·2	A.51-9	Kocharekar, 1955
Rajasthan (south)	Vana	31·1	30·8 to 31·2	*Indore 1*	Simlote, 1956
Uttar Pradesh	Cawnpore-American	35	33	*216F*	Anon., 1956a
Punjab	Upland: *216F*	33·2	35·4	*H.14*	Negi and Avtar Singh, 1956: Negi, 1956
	,, : L. S. S.	30 to 36	34·6	*320F*	*: Negi and Sehgal, 1957

See note to Table 45.

TABLE 47. STAPLE LENGTH OR MEAN FIBRE LENGTH OF THE DIFFERENT *hirsutum* COTTONS

State	Early types	Value (inches)	Value (inches)	Later types	References
Madras	Winter Season:				
	Cambodia: Co. 2	0·911	0·986	*M.C.U.1*	*
	Summer Season:				
	Co. 4	0·94	1·12	*M.C.U.2*	Jagannatha Rao, Marar and Santhanam, 1953
Mysore	Upland: Dharwar-American	(0·74)	0·936	*Laxmi*	Kelkar and Kaiwar, 1954:*
	Mysore-American 2	(7/8)	(1-1/8)	*M.A.5*	Dorasami and Srinivasa Ayyangar, 1948; Anon., 1956a
Andhra Pradesh and Bombay	Parbhani-American Local	(24/32)	(28/32)	*P.A.1*	Anon., 1956a
Bombay	Buri 107	(28/32)	(28/32) to (30/32)	*B. 0394*	,,
			1·14	*134-Co.2-M*	Bhat and Patel, 1955
Madhya Pradesh					
Malwa	Dhar Cambodia	0·85	0·89	*Indore 2*	Simlote, 1956
Nimar	*Buri 0394*	1·08	0·92	A.51-9	Kocharekar, 1955
Rajasthan (south)	Vana	0·80	(0·85 to 0·92)	*Indore 1*	Simlote, 1956
Uttar Pradesh	Cawnpore-American	(23/32)	(28/32 to 30/32)	*216F*	Anon., 1956a
Punjab	Upland: 216F	0·93	0·95	*H. 14*	Negi and Avtar Singh, 1956: Negi, 1956
	,, : L. S. S.	0·897	0·91	*320F*	* :Negi and Sehgal, 1957

See note to Table 45.
Staple length values are entered within parenthesis.

TABLE 48. MEAN FIBRE WEIGHT PER INCH (10^{-6} oz.) OF THE DIFFERENT *hirsutum* COTTONS

State	Early types	Value	Value	Later types	References
Madras	Winter Season:				
	Cambodia: Local	0·137	0·123	Co.3	Kalyanaraman, 1954:*
			0·149	*M.C.U.1*	*
	Summer Season:				
	Co. 4	0·136	0·105	*M.C.U.2*	Jagannatha Rao, Marar and Santhanam, 1953
Mysore	Upland: Gadag 1	0·149	0·128	*Laxmi*	*
	Mysore-American 2	0·179	0·155	*M.A.5*	Dorasami and Srinivasa Ayyangar, 1948
Andhra Pradesh and Bombay	Parbhani-American Local	0·283	0·131 to 0·144	*P.A.1*	Anon., 1956a;*
Bombay	Buri 107	0·151	0·142 to 0·146	*B. 0394*	Anon., 1956a:*
			0·123	*134-Co.2-M*	Bhat and Patel, 1955
Madhya Pradesh					
Malwa	Dhar Cambodia	0·138	0·154	*Indore 2*	Simlote, 1956
Nimar	*Buri 0394*	0·128	0·124	A.51-9	Kocharekar, 1955
Rajasthan (south)	Vana		0·143	*Indore 1*	Simlote, 1956
Uttar Pradesh	Cawnpore-American	0·163	0·146	Perso-American	Anon., 1956a: Sethi, 1947
			0·148	*216F*	Anon., 1956a
Punjab	Upland: 216F	0·151	0·150	*H. 14*	Negi and Avtar Singh, 1956: Negi, 1956
	,, : L.S.S.	0·153	0·148	*320F*	*: Negi and Sehgal, 1957

See note to Table 45.

TABLE 49. SPINNING CAPACITY OF THE DIFFERENT *hirsutum* COTTONS

State	Early types	H.S.W.C.	H.S.W.C.	Later types	References
Madras	Winter Season:				
	Cambodia: Local	30	43·3	*M.C.U.1*	Kalyanaraman, 1954:*
	Summer Season:				
	Co. 4	41	66	*M.C.U.2*	Jagannatha Rao Marar and Santhanam, 1953
Mysore	Upland: Dharwar-American	20	47·2	*Laxmi*	Kelkar and Kaiwar, 1954: *
	Mysore-American 2	34	36	*M.A.5*	Dorasami and Srinivasa Ayyangar, 1948
Andhra Pradesh and Bombay	Parbhani-American Local	(12 to 14 wm)	(24 to 28 wm)	*P.A.1*	Anon., 1956a
			34	*P.A.1*	*
Bombay	Buri 107	(24 wm)	(28 wm)	*B. 0394*	Anon., 1956a
			40	*B. 0394*	*
			44·2	*134-Co.2-M*	Bhat and Patel, 1955
Madhya Pradesh					
Malwa	Dhar Cambodia	24	30	*Indore 2*	Simlote, 1956
Nimar	*Buri 0394*	40	33 (estimated)	A.51-9	Kocharekar, 1955
Rajasthan (south)	Vana	14	26 to 43	*Indore 1*	Gadkari, 1954; Simlote, 1956
Uttar Pradesh	Cawnpore-American	(25 to 30 wm)	(32 wm)	*216F*	Anon., 1956a
	Cawnpore-American 9	34	30	*216F*	* : Sethi and Dharmarajulu, 1957
Punjab	Upland: 216 F	33	39	*H. 14*	Negi and Avtar Singh, 1956
	,, : L. S. S.	38·8	38·7	*320F*	* : Negi and Sehgal, 1957

See note to **Table 45.**

wm: **Approximate mill spinning warp count.**

TABLE 50. INDIAN COTTONS

Species and Variety; State and Tract	Year of evolution (e) release (r)	Station where bred out, tested or maintained	Yield seed cotton (lb./acre)	Ginning percentage	Mean fibre length, (Staple length) (inches)	Mean fibre weight per inch (10^{-6} oz.)	Spinning capacity H.S.W.C. (Approx. count: y=yarn w=warp m=mill spinning)	References
Gossypium arboreum								
OOMRAS								
Vidarbha area,								
Bombay State								
Jadi Mixture	Original		*c. 174* (commercial)	*c.* 35	(5/8 to 7/8)		(10y)	Mollison, 1903; Anon., 1919
Roseum				36 to 40	(4/8 to 11/16)		(8 to 10w)	†
Verum 262	1924(e)	Akola	350 to 750	32 to 35	0·816 [14]	0·176 [12]	22·6 [14]	*
		Nagpur	Av. 500		0·827 [15]	0·180 [12]	24·9 [15]	*
Late Verum	1929(e) *c.* 1932(r)		400 to 800	29 to 30	0·80 [12]	0·179 [12]	30·6 [12]	*
Verum 434	1931(e) 1933(r)	Akola	*391·8* [6]	*c.* 30 to 32	0·851 [16]	0·179 [16]	27·3 [16]	*
H. 420	1935(e) 1949(r)	,,	Av. 507	*c.* 31 to 33	*0·87* [4]	*0·187* [4]	*26·7* [4]	* ; Anon., 1956a
				33 to 34	*0·88* [12]	*0·173* [12]	*31·2* [12]	Kolte, 1954
No. 91	1950(r)			35 to 36	(25/32 to 27/32)		(26 to31wm)	Sethi, 1957
Malini (M.5A)	1954(*r*)			34	(27/32)		(39w)	Bhatt and Shrivastava, 1956; Sethi, 1957
Khandesh tract,								
Bombay State								
Jadi Mixture	Original		500	*c.* 35	0·50		(6 to 8w)	Khadilkar, 1947b
N. Roseum 6	1926(r)		615 [8]	40	0·65	0·262	6	Khadilkar, 1950
Banilla	1932(r)		676 [8] (if not damaged by wilt)	38·5	0·75	0·180	16	,,

TABLE 50. (*Contd.*)

Species and Variety; State and Tract	Year of evolution (e) release (r)	Station where bred out, tested or maintained	Yield seed cotton (lb./acre)	Ginning percentage	Mean fibre length, (Staple length) (inches)	Mean fibre weight per inch (10^{-6} oz.)	Spinning capacity H.S.W.C. (Approx. count: y=yarn w=warp m=mill spinning)	References
Khandesh tract, Bombay State (*Contd.*)								
Jarila	1930(e) 1937(r)	Jalgaon	*471·8* [4]	34 to 37	0·850 [21]	0·165 [21]	29·5 (21)	*
Virnar	1939(e) 1949(r)	,,	*481·0* [4]	37 to 39	*0·88* [4]	*0·181* [4]	*28·7* [4]	*
Mathio tract, Bombay State								
Lalio (*herbaceum*)	Original			c. 31 to 33	(5/8 to 6/8)	—	(30y)	Anon., 1919; Mollison, 1903
Jadi Mixture	Original	Amreli	452 [3]	31·6	0·80	0·198	15	Phadnis, 1957
Pratap	1945(e) 1947(r)	,,	396 [3]	34·3	0·85	0·167	28	Phadnis, 1957; Patel and Patel, 1948; Anon., 1956a
C. J. 73	1949(e)	,,	474 [3]	34·6	0·907	0·154	38	Phadnis, 1957; Anon., 1956a
Malvi tract, Madhya Pradesh								
Malvi Local	Original		380	28·9	0·70	0·199	12	Gadkari, 1954; Simlote, 1956
Malvi 9	1935(r)	Indore	328 to 441	31·5 to 32·5	0·79 to 0·85	0·169 to 0·194	17 to 20	,,
Bhoj	1942(r)	,,	328 to 378	31·5 to 32·7	0·77	0·163	21	,,
Local Nimari	Original	Khargone	367 [4]	30·2	0·83	0·156	26	Kocharekar, 1955
(Jarila)		,,	405 [4]	32	0·86	0·168	26	,,
(Virnar)		,,	562 [4]	38·4	0·84	0·184	24	,,
Maljari	1948(e) 1954(r)	,,	662 [4]	36·7	0·86	0·174	30	,,

Gaorani tract, Bombay, Mysore and Andhra Pradesh States								
Gaorani or Bani	Original		*c. 320* (commercial)	*c.* 25	(1 to 1-1/8)	—	(40y)	Anon., 1919; Mollison, 1903
Umri Bani	Original		250 to 300 (commercial)	28 to 29	0·821 [22]	0·172 [17]	27·9 [22]	*
Gaorani 6	1930(e) 1936(r)	Nanded	426 [22]	*c.* 30 to 33	0·831 [15]	0·162 [15]	32·3 [15]	*
1494		,,	472 [3]	34·5	0·98	0·157	39	Bederker, 1955b
1585		,,	469 [3]	38·3	0·87	0·171	32	,,
Gaorani 12	1950(r)	Parbhani	576 [1]	32	0·90 [1]	0·171 [1]	39 [1]	*
Daulat (2204)	1945(e) 1955(r)	,,		36·8	0·89	0·174	37	Joshi, 1956b
1422		Nanded	485 [3]	37·5	0·88	0·164	34	Bederker, 1955b
BENGALS								
Punjab State								
Mixture	Original		900	35	(19/32)	0·310	(6wm)	Anon., 1956a
39 Mollisoni		Jullundur	*c. 1315* [4]	36 to 38	*0·73* [3]	*0·289* [3]	*8* [3]	*
M.60A-2			*c. 1081* [6]	38·7	0·67	0·291	6	Negi and Avtar Singh, 1956
231 R	1953(r)		1168	43	(5/8)	0·324	(6wm)	Anon., 1956a; Sethi, 1957
Uttar Pradesh State								
Mixture	Original		650	*c.* 31 to 34	0·70	0·250	10	Anon., 1956a; Sethi and Ansari, 1943
Bundelkhand J N. 1 or Jalaun 1	1920(r)	Kanpur	*c. 603* [3]	36	0·761 [7]	0·237 [5]	12·7 [7]	*
Aligarh 19	1917(e) 1921(r)	Aligarh	*c.* 763 [8]	36 to 38	0·672 [16]	0·283 [11]	6·5 [16]	*
C.402	1922(e)	Hardoi	*c.* 641 [4]	37 to 39	0·804 [9]	0·188 [9]	18·2 [9]	*
C.520	1931 (r)		708	*c.* 35	0·76	0·220	13	Sethi and Ansari, 1943; Sethi, 1947; Anon., 1956a
35/1	1940(r)		714	36 to 37	(23/32 to 24/32) (0 82) (26/32)	0·211	(13 to 19 wm)	† ; Anon., 1956a; Sethi, 1957
Rajasthan State								
Southern Area								
Vani	Original		710	33	(17/32)	0·228	(8 to 11 wm)	Anon., 1956a
Northern Area								
C. 520		Ganganagar	1083	35·8	0·72	0·234	9·5	Simiote, 1956
Ganganagar 1	1942(*e*)	,,	1155	40·3	0·70	0·239	10·5	,,

TABLE 50. (*Contd.*)

Species and Variety; State and Tract	Year of evolution (e) release (r)	Station where bred out, tested or maintained	Yield seed cotton (lb./acre)	Ginning percentage	Mean fibre length, (Staple length) (inches)	Mean fibre weight per inch (10^{-6} oz.)	Spinning capacity H.S.W.C. (Approx. count: y=yarn w=warp m=mill spinning)	References
SOUTHERNS								
Karunganni tract,								
Madras State								
Karunganni	Original			27·4			(20y)	Mollison, 1903
Tinnies: Local Mixture	Original		*c. 366* (commercial)	27	(6/8 to 7/8)			Anon., 1919
Company 2	1915(e)							Anon., 1954
Company 3	1915(e)							,,
A.10	*c.* 1921							,,
C.7	*c.* 1921(*r*)	Koilpatti	483 [20]	28 to 32 (30 normally)	0·836 [20]	0·171 [15]	25·2 [20]	* ; Anon., 1954
K.1	1929(e) 1934(r)	,,	424 [17]	29 to 36	0·819 [15]	0·179 [15]	21·0 [15]	*
K.2	1939(e) 1947(r)	,,	*c. 229* [4]	*c.* 30 to 33	*0·87* [4]	*0·169* [4]	29·7 [4]	* ; Anon., 1956a
K.5	1944(r)	Coimbatore	271·5 [8]	27 to 31	0·898 [8]	0·180 [8]	30·2 [8]	*
6186-9			329	31·4	0·95	0·187 to 0·200	34-36	Kalyanaraman, Neelakantan and Iyemperumal, 1954 ; I.C.C.C. Publicity Note, 1957
Northerns tract,								
Andhra Pradesh								
Red and White Northerns	Original		400	22	(26/32 to 28/32	0·168	(22 wm)	Anon., 1956a
N. 14	1918(*r*)	Nandyal	*c. 273* [27]	22 to 26	0·894 [31]	0·168 [26]	36·7 [31]	*

Strain 122		,,	113*x*	32	0·86			Seshadri Ayyangar, Nageswara Rao and Rama Rao, 1956
N. 14			100*x*					
Cocanadas tract, Andhra Pradesh								
Palnad (Cocanadas) Local	Original		*c. 543*	25	0·79	0·174	25	Jagannatha Rao, Marar and Santhanam, 1953
Cocanadas 1	1947(r)		*c. 695*	28	0·87	0·189	35	,, ; Anon., 1956a
Cocanadas 2 (336B)	*c.* 1948(e)		*c. 700*	30	0·89	0·194	35	,, ; ,,
R.H. 25	1951(r)		*c. 700*	29	0·86	0·190	28	,,
Mungari tract, Andhra Pradesh and Mysore States								
Jadi Mixture	Original	Adoni	100*x*	35	0·80	0·222	14	Seshadri Ayyangar and Venkoba Rao, 1957
Rayalaseema 1 (881F)	1952(r)	,,	105*x*	33	0·88	0·192	29	,, ; Anon., 1956a
3930A		,,	106*x*	35	0·94	0·201	34	,,
3943B		,,	126*x*	34	0·98	0·173	40	,,
Chinnapathi, Andhra Pradesh and Orissa States Local	Original		250 to 300	25	(17/32 to 20/32)	0·193	(8 to 10 wm)	Anon., 1956a
Comillas tract, Assam and Tripura States								
Comillas			85	47	(12/32 to 14/32)	0·380	(8 to 10 wm)	,,
Assam Local (*cernuum* and other cottons)				29 to 56	0·4 to 0·9		6 to 18	Barooch and De, 1950
Gossypium herbaceum								
South Gujerat, Bombay State								
Surti Local	Original	Surat	505	34·8	0·85	0·232	20 to 24	Pandya, Majumdar and Desai, 1956
1A L. B.	1920(r)	,,		*c.* 39	0·88			,, ; Patel, G.B., 1947

TABLE 50. (*Contd.*)

Species and Variety; State and Tract	Year of evolution (e) release (r)	Station where bred out, tested or maintained	Yield seed cotton (lb./acre)	Ginning percentage	Mean fibre length, (Staple length) (inches)	Mean fibre weight per inch (10^{-6} oz.)	Spinning capacity H.S.W.C. (Approx. count: y=yarn w=warp m=mill spinning)	References
South Gujerat, Bombay State (*Contd.*)								
1027A L. F.	1918(e) 1924(r)	Surat	c. *509* [24]	c. 31 to 37	0·952 [31]	0·183 [26]	32·5 [31]	*
Suyog	1946(r)	,,	c. *403* [7]	c. 34 to 38	0·971 [7]	0·192 [7]	34·7 [7]	*
Vijalpa (2087)	1952(r)	,,	523 [3]	36	0·94	0·170	37	Pandya, Majumdar and Desai, 1956
Mid-Gujerat, Bombay State Broach Desi				c. 32 to 37	(5/8 to 6/8)		(20y)	Anon., 1919; Mollison, 1903
Broach Local or Kanvi		Broach	581	41·6	0·75	0·220	13	Patel, P. L., 1947
B. D. 8		,,	490	33·8	0·90	0·179	38·5	,,
Vijay	1943;	,,	514 [8]	41·2	0·87	0·167	38	,, ; Anon., 1956a
	1946(r)		*823* [4]	c. 36 to 42	*0·91* [4]	*0·167* [4]	*42·2* [4]	*
Digvijay (98-41)	1956(r)	,,	546 [4]	38·8	0·91	0·147	43	Thakar, 1955; Anon., 1957c
North Gujerat (including Kathiawar and Kutch), Bombay State								
Wagad (Local)	Original	Viramgam	424 [10]	34·4	0·80	0·211	14·5	Patel, S. J., 1949
Wagad 4	1921(e)	,,	592 [1]	37	0·822 [4]	0·227 [4]	16 [4]	*
Wagad 8	1921(e) c. 1930(r)	,,	c. *603* [16]	c. 33 to 43	0·789 [20]	0·232 [16]	13 [20]	*
Wagotar	1943(r)	,,	440 [10]	41·5	0·80	0·193	17·5	Patel, S. J., 1949; Anon., 1956a
Kalyan	1947(r)	,,	637 [5]	39·9	0·85	0·182	27	,,

Kumpta tract, Mysore State								
Kumpta local	Original		352	23 to 24	(26/32 to 28/32)	0·193	(22 wm)	Anon., 1956a
		Dharwar	524	25·4	0·83		24	Tippannavar and Pat 1952
Dharwar 1	1914(e) 1918(r)	,,	*c.* 300 (normally)	29	0·879 [8]	0·195 [5]	32·7 [8]	* ; ,,
Jayawant	1928(r)	,,	*c. 548* [17] (*c.* 300 normally)	*c.* 23 to 31 (28 to 29 normally)	0·903 [27]	0·176 [24]	37·5 [27]	* ; ,,
Jayadhar	1948(r)	,,	*c. 651* [5]	*c.* 29 to 32	0·918 [5]	0·176 [5]	43 [5]	* ; ,,
R. K. 19				28 to 29	(0·81)		(24w)	†
Selection 69	1942(r)		280	30	(24/32 to 26/32)	0·180	(32w, 20wm)	† : Anon., 1956a; Sethi, 1957
Westerns tract, Mysore and Andhra Pradesh States								
Westerns Local			*c. 208* (commercial)	*c.* 25	(6/8)		(20w)	Anon., 1919; Satyanarayana Murthy, Venkoba Rao and Jagannatha Rao, 1955b
Hagari 25	1917(r)	Hagari	238 [7]	25 to 30	0·873 [10]	0·182 [4]	28·8 [10]	*
Westerns **1**	1926(r)	,,	*c. 231* [22]	*c.* 28 to 32	0·859 [29]	0·174 [25]	29·8 [29]	*
Gossypium hirsutum								
Madras State: Winter								
Cambodia	Acclimatised		*c. 510* (commercial)	33	(5/8 to 1-1/8)	0·137	30	Anon., 1919; Kalyanaraman, 1954
Co.1	1921(r)	Coimbatore	500	35	0·902 [8]	0·147 [6]	32·6 [8]	*
Co.2	1921	,,	*c. 707* [15]	30 to 36	0·911 [31]	0·142 [26]	32 [31]	*
Co.3		,,	*c. 957* [6]	36 to 38	0·923 [6]	0·123 [6]	42·5 [6]	*
4463								Anon., 1954; Kalyanaraman, 1954, 1955
M.C.U. 1	1950(r)		*c. 1037* [2] (715 commercial)	*c.* 36 to 38	*0·986* [3]	*0·149* [3]	*43·3* [3]	* ; Sethi, 1957

TABLE 50. (*Contd.*)

Species and Variety; State and Tract	Year of evolution (e) release (r)	Station where bred out, tested or maintained	Yield seed cotton (lb./acre)	Ginning percentage	Mean fibre length, (Staple length) (inches)	Mean fibre weight per inch (10^{-6} oz.)	Spinning capacity H.S.W.C. (Approx. count: y=yarn w=warp m=mill spinning)	References
Madras State: Winter—(*Contd.*)								
(Co. 2)			100*x*					Jagannatha Rao, Marar and Santhanam, 1953
9030			124*x*	37	0·97	0·124	40	
Madras State: Summer								
Co. 4		Coimbatore	*c. 757*	37	0·94	0·136	41	,,
M.C.U.1			*c. 936* [6] (600 to 800 commercial)	*c.* 32 to 36	1·007 [9]	0·131 [9]	50·1 [9]	*
M.C.U.2 (7682)	1955(r)		104*x*	33	1·12	0·105	66	Jagannatha Rao, Marar and Santhanam, 1953; Sethi, 1957
(Co. 2)			100*x*					
Mysore State								
Dharwar-American	Acclimatised		323 [3]	28	(0·74)		20	Kelkar and Kaiwar, 1954
Upland Gadag No. 1	1914(e) 1918 (r)	Gadag	*c. 443* [13]	*c.* 31 to 34	0·832 [29]	0·149 [24]	33·4 [29]	*; Tippannavar and Patil, 1952
Laxmi	1948		*c. 391* [6]	*c.* 35 to 37	0·936 [5]	0·128 [5]	47·2 [5]	* ; ,,
Mysore-American 2	1928(e)	Babbur	*c. 990* [2]	30	(7/8)	0·179	34	Dorasami and Srinivasa Ayyangar, 1948
Mysore-American 5	1945(r)		*c. 813*	35	(1-1/8)	0·155	36	,, ; Anon., 1956a

Andhra Pradesh and Bombay States								
Parbhani-American Local	Acclimatised		250	32	(24/32)	0·283	(12 to 14wm)	Anon., 1956a
Parbhani-American 1	1932(e) 1950(r)	Parbhani	250 to 456	c. 30 to 33	0·96 (28/32)	0·131 to 0·144	34 (24 to 28wm)	* ; Anon., 1956a
Bombay State								
B. 107			342	c. 28	(28/32 to 30/32)	0·151	(40w) (24 wm)	Anon., 1956a; Bhatt and Shrivastava, 1956
B. 0394	1950(r)		504 to 865	32 to 34	*0·93* [2] (28/32 to 30/32)	0·142 to 0·146	*40* [2] (28 wm)	Anon., 1956a; *
170-Co.2	1952(r)	Surat	c. *413* [4]	*38·5* [4]	*1·04* [4]	*0·137* [3]	*42·3* [3]	Bhat and Patel, 1955; Anon., 1956a
134-Co.2-M	1952(r)	,,	c. *221* [5]	*33·3* [5]	*1·14* [5]	*0·123* [4]	*44·2* [4]	,,
Madhya Pradesh								
Malwa Upland								Simlote, 1956
Dhar Cambodia	Acclimatised	Indore	423	30·6	0·85	0·138	24	,,
Upland: Indore 2	1950(r)	,,	478	32·8	0·89	0·154	30	,,
Nimar: Buri 0394		Khargone	1001 [1]	31·9	1·08	0·128	40	Kocharekar, 1955
A.51-9		,,	1157 [1]	37·2	0·92	0·124	33 (estimated)	,,
Rajasthan (south)								
Vana Mixture		Udaipur	931	31·1	0·80		14	Gadkari, 1954; Simlote, 1956
Upland: Indore 1	1934(r)	,,	990 to 1106	30·8 to 31·2	(0·85 to 0·92)	0·143	26 to 43	,,
Uttar Pradesh								
Cawnpore-American	Acclimatised	Cawnpore (Kanpur)	433	35	(23/32)	0·163	(25 to 30wm)	Anon., 1956a
Cawnpore-American 9	1917(r)	,,	c. *617* [4]	c. 30 to 31	0·868 [9]	0·152 [4]	34 [9]	*
Perso-American			680	c. 32	0·88 (28/32)	0·146	32 (30wm)	Sethi, 1947; Anon., 1956a
216F	1948(r)		766	33	(28/32 to 30/32)	0·148	30 (32wm)	Anon., 1956a; Sethi and Dharmarajulu, 1957; Sethi, 1957

TABLE 50. *(Contd.)*

Species and Variety; State and Tract	Year of evolution (e) release (r)	Station where bred out, tested or maintained	Yield seed cotton (lb./acre)	Ginning percentage	Mean fibre length, (Staple length) (inches)	Mean fibre weight per inch (10^{-6} oz.)	Spinning capacity H.S.W.C. (Approx. count: y=yarn w=warp m=mill spinning)	References
Pakistan: Punjab Upland:	Acclimatised		*c. 435* (commercial)	32 to 33	(28/32)			Anon., 1919
India: Uplands: 216F	1948 (r)	Hansi	*c. 1207* [11]	33·2	0·93	0·151	33	Negi and Avtar Singh, 1956
H.14	1955(r)	,,	*c. 1141* to 1267	35·4	0·95	0·150	39	Negi, 1956; Anon., 1956a
Labh Singh Selection (L.S. S.)	1932(r)	Abohar	*c. 1051* [7]	30 to 36	0·897 [6]	0·153 [6]	38·8 [6]	* ; Negi, 1956
320F	1951(r)	,,	*c. 1576* [6]	34·6	0·91	0·148	38·7	Negi and Sehgal, 1957

Note : Values printed in italics are computed from the given data.
Figures within [ ] accompanying each value indicate the number of seasons for which tests for the character were made.
Varieties printed in italics are not released so far for general cultivation.
* Technological Reports on Standard Indian Cottons.
† Wealth of India (see note to Table 36).

respect of spinning capacity. 216F, though a better ginner than Cawnpore-American 9, one of the early improved *hirsutums* of Uttar Pradesh, is a little inferior to the latter in spinning value (Table 49). Similarly the latest strain, A.51-9 of Nimar tract in Madhya Pradesh, in comparison with the type Buri 0394 under cultivation there at present, is a better ginner but a poorer spinner probably owing to its lesser fibre length (Table 49).

Improved spinning of the types, M.C.U.2, Laxmi, M.A.5, P.A.1, Buri 0394 and 134-Co.2-M, is due to improvement both in length and fineness of their fibres (Tables 47, 48, 49 and 50). In the case of the other latest *hirsutums* amelioration in fibre length and not fibre fineness appears to have stepped up their spinning value ; in the types M.C.U.1 and Indore 2 improved spinning is in spite of increased fibre weight per unit length.

Lately, Negi and Aujla (1956) have reported isolation of *hirsutum* strains in the Punjab possessing fibres longer and finer than those of the types at present under cultivation and hence capable of spinning to as high as 56's warps.

IMPROVED VARIETIES—THEIR CHARACTERISTICS AND DISTRIBUTION

The following is a species-wise account of some of the important varieties of cotton in India, as adapted from "A Guide to Indian Cottons," a publication of the Indian Central Cotton Committee, Bombay, (Anon., 1956a).

Gossypium arboreum

1. *M.60A.2*: This is a selection from local bulk in the Punjab. Sowing period April to July, picking period September to January, yield 1,029 lb. of seed cotton per acre, staple length 20/32 inch, lint percentage 38, fibre weight per inch 0·304 (millionth of an ounce) average mill spinning capacity 6, blow room loss percentage 9. This variety is grown in Hissar, Rohtak, Karnal and Gurgaon districts of the Punjab.

2. *Rosea 231* (*231R*): This is another selection from local bulk in the Punjab. Sowing period April to July, picking period September to January, yield 1,168 lb. of seed cotton per acre, staple length 20/32 inch, lint percentage 43, fibre weight per inch 0·324 (millionth of an ounce), average mill spinning capacity 6, blow room loss percentage 8. Grown in Hoshiarpur, Ambala, part of Gurdaspur, Jullundur and Ludhiana districts of the Punjab.

3. *Ganganagar 1* (*Rohilkhand Selection R.18*) : This is a selection from Uttar Pradesh survey material. Sowing period April to July, picking period September to January, yield 656 to 820 lb. of seed cotton per acre, staple length 20/32 inch, ginning percentage 40, fibre weight per inch 0·250 (millionth of an ounce), average mill spinning capacity 8 to 11, blow room loss percentage 6 to 10. Suited for cultivation in Ganganagar Canal area, Tonk and Jaipur districts and some parts of Sawai Madhopur district of Rajasthan.

4. *C.520* : This variety is a selection from local bulk in Uttar Pradesh. Sowing period April to July, picking period September to November, yield 708 lb. of seed cotton per acre, staple length 23/32 to 24/32 inch, ginning percentage 35, fibre weight per inch 0·220 (millionth of an ounce), average mill spinning capacity 8 to 12, blow room loss percentage 9. This has been replaced by 35/1 and is out of cultivation in Uttar Pradesh, but is fairly widespread in Tonk and Jaipur districts and some parts of Sawai Madhopur district of Rajasthan.

5. *35/1*: This is selected from Uttar Pradesh survey material. Sowing period April to July, picking period September to January, yield 714 lb. of seed cotton per acre, staple length 26/32 inch, ginning percentage 37, fibre weight per inch 0·211 (millionth of an ounce), average mill spinning capacity 16, blow room loss percentage 6. Grown in Saharanpur, Muzaffarnagar, Bijnor, Meerut and Moradabad districts of Uttar Pradesh.

6. *Malvi 9* : This is a selection from local Malvi (Madhya Pradesh) and was released for general cultivation in 1935. Sown in the last week of June and picked during the period October to December. This variety is susceptible to wilt (*Fusarium vasinfectum*). It has given higher ginning outturn and higher spinning value than the local Malvi. Yield 375 to 450 lb. of seed cotton per acre, staple length 22/32 to 24/32 inch, ginning percentage 33, fibre weight per inch 0·208 (millionth of an ounce), average mill spinning capacity 14 to 16, blow room loss percentage 11. This variety is recommended for cultivation in Rajgarh, Shajapur, Ujjain, Ratlam, Mandsaur, Dewas, Indore, Khargone, Dhar, Jhabua and Bhopal districts of Madhya Pradesh; Nimbahera and Pratabgarh *talukas* of Chittore district and parts of Jhalawar district of Rajasthan State.

7. *Bhoj* : This also is a selection from local Malvi (Madhya Pradesh) and was released for cultivation in 1942. Sowing period June, picking period October to December. This is *c.* 88 per cent. wilt-resistant. Yield 410 to 490 lb. of seed cotton per acre, staple length 26/32 inch, ginning percentage 32, fibre weight per inch 0·187 (millionth of an ounce), average mill spinning capacity 23, blow room loss percentage 10. Grown in the same tracts in which Malvi 9 is grown.

8. *Maljari (D.48-154)* : This strain, a selection from Malvi 9 x Jarila, was released in Madhya Pradesh for general cultivation in 1954 and yielded seed cotton and lint per acre more than the local Nimari and compared favourably with Jarila in fibre properties. Sowing period last week of June, picking period October to December. This is less susceptible to wilt attack, withstands damage from the drought or heavy rains. The crop in Nimar area ripens a fortnight earlier than that in Malwa area. Yield 413 to 880 lb. of seed cotton per acre, staple length 26/32 inch, ginning percentage 35, fibre weight per inch 0·170 to 0·185 (millionth of an ounce),

average mill spinning capacity 30, blow room loss percentage 8. Recommended for the same tracts in which Malvi 9 and Bhoj are grown.

9. *Jarila*: This is a selection from Verum cotton isolated in 1930 in Khandesh tract of Bombay State. This had occupied the entire Khandesh tract by 1942. It could not withstand late rains. It became unpopular with the cultivators on account of its decline in yield over a series of changed seasons. Sowing period June, picking period November to January, resistant to wilt. Yield 490 lb. of seed cotton per acre, staple length 24/32 to 28/32 inch, ginning percentage 33 to 35, fibre weight per inch 0·166 (millionth of an ounce), average mill spinning capacity 22 to 24, blow room loss percentage 9 to 13. Though first released in Khandesh tract, its cultivation subsequently spread to the adjoining tracts within Bombay State and also outside in Madhya Pradesh and Rajasthan. Now largely replaced by Virnar.

10. *Virnar*: This is a selection from a cross between N.R.5 x Jarila. It is superior to Jarila in yield and ginning percentage. On account of its late maturity, it withstands adverse seasonal conditions. It was released in Khandesh tract (Bombay State) in 1949. Sowing period June, picking period November to January, yield 500 lb. of seed cotton per acre, staple length 26/32 to 28/32 inch, ginning percentage 38 to 39, fibre weight per inch 0·191 (millionth of an ounce), average mill spinning capacity 20 to 24, blow room loss percentage 6 to 11. It is grown in Nasik, East and West Khandesh, Aurangabad, Akola, Amraoti, Yeotmal, Buldana and Wardha districts of Bombay State and Nimar, Khargone, Rajgarh, Shajapur, Jhabua, Ujjain, Ratlam and Dhar districts of Madhya Pradesh.

11. *V. 434*: A selection from Verum bulk made in 1933 in Nagpur-Berar area of Bombay State. Wilt-resistant. Sowing period June, picking period November to January, yield 350 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 29, fibre weight per inch 0·182 (millionth of an ounce), average mill spinning capacity 20, blow room loss percentage 9. Replaced by H.420.

12. *H. 420*: A selection from the cross, Bani x *cernuum* (Garo Hill cotton) released for general distribution in Nagpur-Berar area (Bombay State) in 1949. This is highly wilt-resistant type and can withstand adverse climatic conditions. Sowing period June to July, picking period October to January. Yield 580 lb. of seed cotton per acre, staple length 28/32 inch, ginning percentage 33 to 34, fibre weight per inch 0·183 (millionth of an ounce), average mill spinning capacity 20 to 24, blow room loss percentage 4. Grown in Wardha, Akola, Amraoti and Yeotmal districts of Bombay State; Nimar district of Madhya Pradesh; parts of Anantapur, Kurnool and Cuddapah districts of Andhra Pradesh and Bellary district of Mysore State.

13. *Pratap*: A selection from local Mathio bulk in Kathiawar (Bombay State). Released for general distribution in 1947. Sowing period last

week of June to beginning of July, picking period October to December, yield 374 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 32, fibre weight per inch 0·175 (millionth of an ounce), average mill spinning capacity 18 to 20, blow room loss percentage 6 to 8. Recommended for Amreli, Ahmedabad (part), Sorath, Gohilwad and Madhya Saurashtra districts of Bombay State.

14. *C. J. 73* : It is a single plant selection made at Amreli (Bombay State) in 1949, from a cross between Cawnpore 520 and Jarila. It has longer staple, spins better and is earlier in boll opening by about a week than Pratap. It is drought-resistant. Sowing period last week of June to beginning of July, picking period October to December, yield 441 lb. of seed cotton per acre, staple length 29/32 inch, ginning percentage 34, fibre weight per inch 0·151 (millionth of an ounce), average mill spinning capacity 30, blow room loss percentage 9 to 12. Can be grown in the same tracts in which Pratap is grown.

15. *Gaorani 6* : A selection from the indigenous Gaorani (Bani) cotton in Bombay State. Released for general distribution in 1936. Sowing period June, picking period October to December, yield 421 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 32, fibre weight per inch 0·172 (millionth of an ounce), average mill spinning capacity 26 to 28, blow room loss percentage 6 to 10. Grown in Nanded district, Hingoli, Kalamnuri and Basmat *talukas* of Parbhani district of Bombay State and Nirmal *taluka* of Adilabad district of Andhra Pradesh.

16. *Gaorani 12* : Also a selection from Bani type of cotton, made at Parbhani (Bombay State) and released for distribution in 1950. It is an early type and fairly resistant to wilt. Sowing period June, picking period October to December, yield 311 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 31, fibre weight per inch 0·161 (millionth of an ounce), average mill spinning capacity 26 to 28, blow room loss percentage 6 to 10. Grown in Osmanabad and Aurangabad districts; Moominabad *taluka* of Bhir district; and Parbhani, Gangakhed and Jintur *talukas* of Pharbhani district of Bombay State.

17. *Daulat (2204)* : This is a reselection from Gaorani 12 made in Bombay State. It is a better ginner than Gaorani 12. It was released for general distribution in 1955. Sowing period June, picking period October to December; yield 330 lb. of seed cotton per acre, staple length 28/32 inch, ginning percentage 36, fibre weight per inch 0·165 (millionth of an ounce), average mill spinning capacity 20 to 32, blow room loss percentage 2 to 4. Recommended for cultivation in Parbhani district of Bombay State.

18. *Rayalaseema 1 (881F)* : A selection isolated at Adoni (Andhra Pradesh) from the culture C.6-3 of the *indicum-cernuum* hybrid material *ex* Coimbatore. Released for cultivation in 1952. Suffers damage due to its late habit. It is finer and possesses longer staple than Mungari local.

Sowing period August to September, picking period January to May, yield 313 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 33, fibre weight per inch 0·203 (millionth of an ounce), average mill spinning capacity 24, blow room loss percentage 4. Grown in parts of Anantapur, Cuddapah and Kurnool (excluding Cumbum and Markapur *talukas*) districts of Andhra Pradesh and Bellary, Raichur (excluding Raichur protected areas) and Gulbarga districts of Mysore State.

19. *N.14* : A selection from local Northern cotton made at Nandyal (Andhra Pradesh). It was given out for distribution in 1918. It is bright white to creamy. It is a low ginner. Sowing period June to October, picking period February to April, yield 376 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 25, fibre weight per inch 0·166 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 8. Grown in Kurnool district (excluding Pattikonda, Adoni, Alur and a major portion of Cumbum and Markapur *talukas*) of Andhra Pradesh.

20. *Cocanadas 1* : Derived from an inter-strain cross, 45 x 171, in Andhra Pradesh. Given out for general distribution in 1947. It is noted for the natural colour of the lint. Sowing period July to September, picking period January to April, yield 585 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 28, fibre weight per inch 0·182 (millionth of an ounce), average mill spinning capacity 18 to 22, blow room loss percentage 6 to 12. Grown in Nellore, Guntur, Krishna, East and West Godavari districts, parts of Vishakhapatnam district, Cumbum and Markapur *talukas* of Kurnool district and Nalgonda district of Andhra Pradesh.

21. *Cocanadas 2*: This was evolved through pure line selection in Palnad Bulk (Andhra Pradesh). It is superior to Cocanadas 1 in intensity of lint colour. Released for general distribution in 1951. Sowing period July to September, picking period January to April, yield 598 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 30, fibre weight per inch 0·184 (millionth of an ounce), average mill spinning capacity 18 to 22, blow room loss percentage 6 to 12. Recommended for cultivation in the same tracts in which Cocanadas 1 is grown.

22. *Karunganni 2*: A derivative from the triple hybrid involving Northerns, *cernuum* and Cocanadas cottons isolated in Madras State. It was found suitable for the Uppam area and was released for cultivation in 1947. Sowing period October to November, picking period March to June, yield 268 lb. of seed cotton per acre, staple length 28/32 to 29/32 inch, ginning percentage 31, fibre weight per inch 0·158 (millionth of an ounce), average mill spinning capacity 26 to 28, blow room loss percentage 7. Grown in Madurai, Ramanathapuram and Tirunelveli districts of Madras State.

23. *Karunganni 5* : A selection from the *indicum-cernuum* hybrid material isolated in Madras State. Released for general distribution in 1944 in the Karunganni areas. Sowing period October to November, picking period March to June, yield 216 lb. of seed cotton per acre, staple length 28/32 to 29/32 inch, ginning percentage 27, fibre weight per inch 0·175 (millionth of an ounce), average mill spinning capacity 26 to 28, blow room loss percentage 6 to 7. Grown in Coimbatore, Salem, Tiruchirapalli and Madurai districts of Madras State.

Gossypium herbaceum

1. *Vijay* : A composite type from the backcross, [B.D.8 x Goghari A.26) x B.D. 8], comprising two segregates, B.C.1-2 and B.C.1-6, was released under this name in middle Gujerat (Bombay State) in 1943. In 1946, however, the Indian Central Cotton Committee decided that only the strain, B.C.1-2 should be distributed under this popular name. It was found to be suitable for black clayey soil. Sowing period June to July, picking priod January to March, yield 481 lb. of seed cotton per acre, staple length 24/32 to 28/32 inch, ginning percentage 39 to 40, fibre weight per inch 0·159 (millionth of an ounce), average mill spinning capacity 24 to 26, blow room loss percentage 5 to 6. Grown in Broach (excluding Ankleshwar, Jhagadia and Dediapada *talukas* and part of Nandod *taluka* lying south of the river Narbada and Hansot, Valia and Sagbara *talukas*), Baroda, Kaira, Sabarkantha and Panch Mahals districts and parts of Ahmedabad district lying south of the river Sabarmati including part of Daskori and City *talukas* and whole of Dehgam *taluka* of Bombay State.

2. *Digvijay* : Derivative from the backcross [(Vijay x 1027A L. F.) x Vijay], released in 1956 in middle Gujerat (Bombay State). Fully resistant to wilt. Sowing period June to July, picking period January to March, yield 503 lb. of seed cotton per acre, staple length 29/32 inch, ginning percentage 39, fibre weight per inch 0·154 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 4 to 5. Recommended for the same tract in which Vijay is grown.

3. *Suyog* : This synthetic type (Seg.8-1) was isolated from the cross (1027A L. F. x Selection 1A Long Boll) in South Gujerat (Bombay State). It was released for general cultivation in 1946. Resistant to wilt to a high degree. Sowing period June to July, picking period January to March, yield 479 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 33 to 36, fibre weight per inch 0·199 (millionth of an ounce), average mill spinning capacity 24 to 28, blow room loss percentage 7 to 8. Grown in Surat district, Ankleshwar, Jhagadia, Dediapada *talukas* and part of Nandod *taluka* lying south of river Narbada and Hansot, Valia and Sagbara *talukas* of Broach district and Nawapur and Akkalkuwa *talukas* of West Khandesh district of Bombay State.

4. *Vijalpa* (*2087*): This is derived from the cross, B.C.1-2 x (B.C. 1-2 x 1027A L.F.). B.C.1-2 is Vijay. Vijalpa, released for South Gujerat (Bombay State) in 1952, is very highly resistant to wilt. Sowing period June to July, picking period January to March, yield 523 lb. of seed cotton per acre, staple length 28/32 to 1 inch, ginning percentage 36 to 37, fibre weight per inch 0·170 (millionth of an ounce), average mill spinning capacity 26 to 30, blow room loss percentage 4 to 8. This has now covered practically the whole area of South Gujerat zone of Bombay State formerly occupied by Suyog.

5. *Wagad 8*: It is a selection from local Wagad of Kutch and Kathiawar area (Bombay State). It was released for distribution by 1930. It is a hardy variety, adapted to a wide range of soil and climatic conditions. Sowing period June to August, picking period January to March. General properties of Wagad cottons other than Kalyan are: yield 607 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 37, fibre weight per inch 0·216 (millionth of an ounce), average mill spinning capacity 14 to 18, blow room loss percentage 12 to 15. Grown in part of Ahmedabad district lying north of Sabarmati river, Mehsana, Banaskantha, Madhya Saurashtra, Zalawad, Sorath and Halar districts of Bombay State.

6. *Kalyan*: This is a derivative from the backcross, (Wagad 8 x Seg. 22-3-1-3) x Wagad 8. It was released for distribution in 1947 in North Gujerat tract of Bombay State. Sowing period June to August, picking period January to March, yield 637 lb. of seed cotton per acre, staple length 26/32 to 27/32 inch, ginning percentage 39 to 40, fibre weight per inch 0·182 (millionth of an ounce), average mill spinning capacity 20, blow room loss percentage 6. Grown in Wagad tract comprising Ahmedabad, Mehsana, Madhya Saurashtra, Zalawad, Sorath and Halar districts of Bombay State.

7. *Jayawant*: A wilt-resistant, good stapled strain from a cross between two selections of Kumpta, Dharwar 1 and Dharwar 2. Evolved at Dharwar (Mysory State). Sowing period August to September, picking period February to April, yield 664 lb. of seed cotton per acre, staple length 26/32 to 29/32 inch, ginning percentage 26 to 29, fibre weight per inch 0·183 (millionth of an ounce), average mill spinning capacity 26, blow room loss percentage 12. Grown in Raichur district (excluding the protected area) and Gulbarga district of Mysore State. Replaced by Jayadhar in other parts of Mysore and Bombay States.

8. *Jayadhar*: A derivative from the cross of K.F.T.12-2-5, a wilt-immune selection from Kumpta cotton, with a strain, 1A.14-3 obtained from a hybrid involving *G. herbaceum* (Dharwar 1) and *G. arboreum* (Rosea). Evolved at Dharwar (Mysore State). Combines all the economic and agronomic characters of 1A.14-3 with complete wilt resistance of K.F.T.12-2-5. Released for distribution in 1948. Sowing period August to September, picking period February to April, yield 498 lb. of seed cotton per acre,

staple length 28/32 to 29/32 inch, ginning percentage 29 to 31, fibre weight per inch 0·191 (millionth of an ounce), average mill spinning capacity 30, blow room loss percentage 10. Cultivated in Chitaldrug, Dharwar, Bijapur and Belgaum districts of Mysore State and South Satara and Kolhapur districts of Bombay State.

9. *Selection 69* : A unit plant selection from Kumpta cotton in southern part of Mysore State. Sowing period August to September, picking period February to March, yield 280 lb. of seed cotton per acre, staple length 24/32 to 26/32 inch, ginning percentage 30, fibre weight per inch 0·180 (millionth of an ounce), average mill spinning capacity 20, blow room loss percentage 3. This is very well suited to the black cotton soils of Mysore State, especially the cotton tracts of Chitaldrug district. Grown purely as a rainfed crop, its cultivation was extended to the black soil tracts in south and central Mysore State and was found to be encouraging.

10. *Westerns 1 (H.1)* : A pure line selection obtained at Hagari (Mysore State) by further selection in Hagari 25 (Westerns) which itself is a pure line selection of local Hingari bulk. General distribution of Westerns 1 began in 1926. Sowing period August to September, picking period January to May, yield 269 lb. of seed cotton per acre, staple length 26/32 inch. Ginning percentage 28, fibre weight per inch 0·195 (millionth of an ounce), average mill spinning capacity 24, blow room loss percentage 10 to 12. Grown in Bellary and Raichur districts of Mysore State, and Gooty and Tadpatri *talukas* of Anantapur district, Proddatur, Jammala and Madugwar *talukas* of Cuddapah district and Pattikonda, Adoni and Alur *talukas* of Kurnool district of Andhra Pradesh.

Gossypium hirsutum

1. *L.S.S.* : This is an improved strain, selected from 4F in the Punjab (Pakistan). Released for general cultivation in 1932. It is a late ripening variety and requires irrigation in the months of October and November. Sowing period April to May, picking period November to January, yield 1,278 lb. of seed cotton per acre, staple length 26/32 to 28/32 inch, ginning percentage 33, fibre weight per inch 0·166 (millionth of an ounce), average mill spinning capacity 24, blow room loss percentage 6 to 10. Grown in Ferozepur district and parts of Bhatinda district of the Punjab.

2. *320F* : This is another improved strain selected from L.S.S. in the Punjab and released for general distribution in 1951. It is superior to L.S.S. in fibre properties and is about a month earlier in maturity, on which account it is fast replacing L.S.S. Sowing period April to May, picking period October to December, yield 1,114 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 34, fibre weight per inch 0·150 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 12.

Grown in Ferozepur, Ludhiana, Jullundur, parts of Hoshiarpur, Amritsar and Gurdaspur districts, Bhatinda (excluding Mansa *tehsil* and Police Station, Maur), Patiala, Kapurthala and part of Sangrur districts of the Punjab.

3. *216F* : This variety, a selection from M.4 of Sind (Pakistan), is the first variety of the Punjab-American cotton, given out for cultivation in the post-Independence period, i.e., after 1947. Released for general distribution in 1948. It is an early ripening variety. Sowing period April to May, picking period October to November, yield 1173 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 33, fibre weight per inch 0·148 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 12. Grown in Hissar, Gurgaon, Rohtak and Karnal districts, Mansa *tehsil* and Police Station Maur of Bhatinda district and Jind and Narwana *tehsils* of Sangrur district of the Punjab; Agra district and parts of Rohilkhand, Meerut and Allahabad Divisions of Uttar Pradesh; and Tanjore, Tiruchirapalli, Madurai, North and South Arcot and Chingleput districts of Madras State.

4. *H. 14* : A reselection from 216 F isolated in the Punjab and released for general distribution in 1955. It is superior to 216F in yield, ginning percentage and fibre properties and matures about two weeks earlier. Sowing period April to May, picking period October to November, yield 1,267 lb. of seed cotton per acre, staple length 30/32 inch, ginning percentage 35, fibre weight per inch 0·142 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 8 to 13. Grown in Hariana tract of the Punjab and Ganga Canal Colony of Rajasthan.

5. *Perso-American* : A pure line selection of an Upland variety which was first imported from Persia into Uttar Pradesh. Sowing period mid-April to mid-May, picking period September to November, yield 680 lb. of seed cotton per acre, staple length 28/32 inch, ginning percentage 32, fibre weight per inch 0·146 (millionth of an ounce), average mill spinning capacity 30, blow room loss percentage 9. Grown in western and central regions of Uttar Pradesh including Agra district and parts of Rohilkhand, Meerut, Bulandshahr, Aligarh, Mathura and Etah districts. Largely replaced by 216F from the Punjab.

6. *Indore 1* : A selection made at the Institute of Plant Industry, Indore, from the locally acclimatized Malwa Upland cotton in Madhya Pradesh. It is slightly resistant to red leaf disease and leaf roller pest. Sowing period April to mid-June, picking period October to January, yield 652 lb. of seed cotton per acre, staple length 26/32 to 28/32 inch, ginning percentage 30, fibre weight per inch 0·152 (millionth of an ounce), average mill spinning capacity 20, blow room loss percentage 10. Grown in Mewar tract comprising a major part of Udaipur Division, Pali district of Jodhpur Division and parts of Ajmer district in Rajasthan.

7. *Indore 2*: This was obtained from X-rayed material of Malwa Upland 4 at Indore (Madhya Pradesh). It was given out for cultivation in 1950. Sowing period June, picking period November to January, yield 600 lb. of seed cotton per acre, staple length 26/32 to 28/32 inch, ginning percentage 31, fibre weight per inch 0·145 (millionth of an ounce), average mill spinning capacity 26 to 28, blow room loss percentage 6. Grown in Rajgarh, Shajapur, Indore, Dhar, Ratlam, Ujjain, Mandsaur, Dewas, Khargone and Jhabua districts of Madhya Pradesh.

8. *Buri 107* : A selection from *hirsutum* cotton acclimatized in Nagpur-Berar area of Bombay State. It is a low ginner and on this account is slowly losing its popularity. Sowing period June to July, picking period November to January, yield 342 lb. of seed cotton per acre, staple length 28/32 inch, ginning percentage 28, fibre weight per inch 0·151 (millionth of an ounce), average mill spinning capacity 24, blow room loss percentage 5. Grown in Nimar districts of Madhya Pradesh and Nagpur, Wardha, Akola, Amravati and Yeotmal districts of Bombay State.

9. *Buri 0394* : This is an improved variety reselected from Buri 107 in Nagpur-Berar area of Bombay State. Released for general distribution in 1950. It has a much higher ginning outturn and also gives a higher yield. Sowing period June to July, picking period November to January, yield 504 lb. of seed cotton per acre, staple length 28/32 to 30/32 inch, ginning percentage 32 to 34, fibre weight per inch 0·142 (millionth of an ounce), average mill spinning capacity 28, blow room loss percentage 4. Grown in Nimar districts of Madhya Pradesh and Nagpur, Wardha, Akola, Amravati and Yeotmal districts of Bombay State.

10. *170-Co.2* : This is an interspecific hybrid derivative obtained from *hirsutum-arboreum* hybridisation at Surat (Bombay State). It was released for general distribution in 1952. Sowing period May to July, picking period February to March, yield: irrigated 1,046 lb., rainfed 348 lb. of seed cotton per acre, staple length 1 to 1-1/8 inch, ginning percentage 36 to 38, fibre weight per inch 0·129 (millionth of an ounce), average mill spinning capacity 36 to 38, blow room loss percentage 5 to 8. Cultivated in Sabarkantha, Kaira, Panch Mahals, Baroda, Broach and Surat districts, Kathiawar region and the Deccan Canal area of Bombay State.

11. *134-Co.2-M* : This is another interspecific hybrid derivative. It has been obtained from *hirsutum-herbaceum* hybridisation made at Surat (Bombay State). It was released for general distribution in 1952 and is particularly suited to the light soils of North Gujerat. Its leaves are broad, big and 4-5 lobed in the initial stage. Bolls are big in size, and elongated with flattened sides. The common pests are jassids, thrips, aphids and leaf roller. Blackarm is also one of the common diseases affecting this cotton. Sowing period May to July, picking period February to March, yield : irrigated 824 lb., rainfed 232 lb. of seed cotton per acre, staple length 1-1/16 to 1-3/16

inch, ginning percentage 34 to 36, fibre weight per inch 0·132 (millionth of an ounce), average mill spinning capacity 36 to 38, blow room loss percentage 5 to 8. Cultivated in Sabarkantha district of Bombay State.

12. *Parbhani-American 1* : This is a single plant selection made in 1932 at Parbhani (Bombay State) from a cultivator's field growing a mixed crop of *hirsutum* and *arboreum*. It is suitable for highland areas with an assured rainfall. It is dull white and silky. It is susceptible to thrips but resistant to jassids. It is somewhat late maturing. Sowing period June to July, picking period October to December, yield 250 to 300 lb. of seed cotton per acre, staple length 28/32 inch, ginning percentage 32 to 33, fibre weight per inch 0·144 (millionth of an ounce), average mill spinning capacity 24 to 28, blow room loss percentage 8 to 10. Grown in highland areas of Aurangabad district (Bombay State) and Adilabad district (Andhra Pradesh), also to a small extent in the States of West Bengal and Orissa.

13. *Laxmi* : A selection from the cross Gadag 1 x Co.2, isolated at Gadag (Mysore State). Released for cultivation in 1949. It shows great resistance to red leaf blight. It is, however, susceptible to blackarm disease. Sowing period August to September, picking period February to May, yield 306 lb. of seed cotton per acre, staple length 29/32 to 30 /32 inch, ginning percentage 36, fibre weight per inch 0·134 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 6. Grown in Belgaum, Bijapur, Dharwar, Raichur, Chitaldrug and Bellary districts of Mysore State and Kurnool, Cuddapah and Anantapur districts of Andhra Pradesh.

14. *Mysore-American 5* : This was isolated in southern Mysore State from a cross between Co.2 and a selection of Uganda cotton and was released for general distribution in 1945. It is an early type, fairly resistant to jassids and blackarm and tolerates slight water-logging. Resistant to red leaf disease. Sowing period March to July, picking period January to March, yield 800 to 1400 lb. of seed cotton per acre, staple length 1-1/32 to 1-1/16 inch, ginning percentage 35, fibre weight per inch 0·138 (millionth of an ounce), average mill spinning capacity 32, blow room loss percentage 6. Grown in Mysore, Hassan, Chikmagalur and Shimoga districts, as a rotational crop in *mungari jowar* areas. Also grown in Mandya district and the Visveswariah Canal irrigated area.

15. *Co.2* : A pure line selection isolated at Coimbatore (Madras State) from acclimatized *hirsutum*, Cambodia. Sowing period September to November (winter crop), picking period March to May, yield 725 lb. of seed cotton per acre, staple length 30/32 inch, ginning percentage 31, fibre weight per inch 0·142 (millionth of an ounce), average mill spinning capacity 24 to 28, blow room loss percentage 5 to 7. Grown in Salem, Coimbatore and Madurai districts of Madras State and Trichur district of Kerala.

16. *Co.4* : This was evolved at Coimbatore (Madras State) by selection from the cross Co.2 x A.12, a South African cotton. Sowing period March (summer crop), picking period September. Yield 900 lb. of seed cotton per acre, staple length 30/32 inch, ginning percentage 34, fibre weight per inch 0·136 (millionth of an ounce), average mill spinning capacity 24 to 28, blow room loss percentage 5 to 7. Grown in Salem, Coimbatore, North Arcot, South Arcot, Tiruchirapalli, and Chingleput districts of Madras State and Trichur district of Kerala State.

17. *M.C.U. 1* (*Rajapalayam*) : This was isolated in Madras State, by selection from Co.4 and is better in staple length and ginning percentage than Co.4. Sowing period March (summer crop), September to November (winter crop), picking period September (summer crop), March to May (winter crop), yield 900 lb. of seed cotton per acre, staple length 1 to 1-1/16 inch, ginning percentage 35, fibre weight per inch 0·133 (millionth of an ounce), average mill spinning capacity 36, blow room loss percentage 8. Grown in Ramanathapuram, Salem, Coimbatore, Madurai, South Arcot, Tiruchirapalli and Tirunelveli districts of Madras State. Also in the Kathiawar region and Poona, Ahmednagar and Sholapur districts of Bombay State.

18. *M.C.U. 2* (*Summer Season*) : A selection isolated in Madras State from multiple interspecific cross involving Cambodia, A.12, U.4 and Sea Island cottons. Sowing period March, picking period September, yield 1200 lb. of seed cotton per acre, staple length 1 to 1-3/32 inch, ginning percentage 32, fibre weight per inch 0·114 (millionth of an ounce), average mill spinning capacity 36 to 38, blow room loss percentage 4 to 7. Grown in Ramanathapuram district of Madras State.

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Note: I.C.C.C. = Indian Central Cotton Committee.

I.C.G.R. = Indian Cotton Growing Review.

P. B. A. = Plant Breeding Abstracts.
(Commonwealth Bureau of Agriculture).

CHAPTER VII

CYTOLOGY

Extensive studies have been conducted on the cytology of *Gossypium* by several research workers. The number of chromosomes characteristic of each of the species has been determined. In some of the species, critical observations on the size and morphology of somatic chromosome complements and also on the nucleoli and their organisers have been recorded. Genom relationships among *Gossypium* species have been investigated by studying meiotic chromosome behaviour in interspecific hybrids, polyploids and polyploid hybrid combinations. Naturally occurring or induced aneuploids and chromosome structure variants have also been studied cytologically; some of them have been employed in genetic investigations. Literature on these different cytological aspects of cotton will be dealt with in this review.

In many instances, cytological and also genetical findings in *Gossypium* have been reported under names of species, varieties or forms that are not currently accepted by taxonomists. In chapters VII and VIII such old nomenclature is indicated by asterisk marks; and the key to currently recognised synonyms (see Silow, 1944a; Hutchinson, Silow and Stephens, 1947; Hutchinson, 1950, 1951, 1954) is presented below.

Old nomenclature			Current nomenclature
G. arboreum	var. *cernuum*		*G. arboreum* race *cernuum*
	var. *nanking*		*G. arboreum*
	var. *neglectum*		
		forma *bengalensis*	*G. arboreum* race *bengalense*
		forma *indica*	*G. arboreum* race *indicum*
	var. *rosea*		*G. arboreum* race *bengalense*
	var. *sanguinea*		*G. arboreum* race *bengalense*
	var. *typicum*		
		forma *bengalensis*	*G. arboreum* race *bengalense*
		forma *burmanica*	*G. arboreum* race *burmanicum*
		forma *indica*	*G. arboreum* race *indicum*
	var. *typicum*		
		(Nanking)	*G. arboreum*
		(Sanguineum)	*G. arboreum* race *bengalense*

Old nomenclature		Current nomenclature
G. cernuum		*G. arboreum* race *cernuum*
G. contextum		
G. darwinii		*G. barbadense* var. *darwinii*
G. davidsonii		*G. klotzschianum* var. *davidsonii*
G. herbaceum	var. *africanum*	*G. herbaceum* race *africanum*
	var. *frutescens*	*G. herbaceum* race *wightianum*
	var. *typicum*	*G. herbaceum*
	var. *wightianum*	*G. herbaceum* race *wightianum*
G. hopi (Hopi cotton)		*G. hirsutum* race *punctatum*
G. indicum		*G. arboreum*
G. nanking		*G. arboreum*
G. nanking	var. *Bani*	*G. arboreum*
G. neglectum		*G. arboreum*
G. obtusifolium	var. *wightiana*	*G. herbaceum* race *wightianum*
G. punctatum		*G. hirsutum* race *punctatum*
G. purpurascens		*G. hirsutum* race *punctatum*
G. sanguineum		*G. arboreum* race *bengalense*
G. schottii		*G. hirsutum* race *punctatum*
G. taitense		*G. hirsutum* race *punctatum*

Chromosome Numbers. On the basis of the cytological results obtained by various workers it has been established that the basic chromosome number in the genus *Gossypium* is $n=13$ and the species are either diploids with $2n=26$ or tetraploids with $2n=52$. The chromosome numbers of various species have been determined by several workers as shown in Table 51. The earliest studies on cytology of cotton plant were made by Balls (1905, 1910) and Gannon (1903). Denham (1924), according to Harland (1939), was however, the first to report the chromosome numbers in the cultivated species of the Old World (*G. arboreum* and *G. herbaceum*) and the New World (*G. hirsutum* and *G. barbadense*). As cited by Zaitzev (1923), on the contrary, the chromosome numbers of the same four species were determined earlier by Nikolajeva (1922-23), but the details were not given. A detailed account of the chromosome number in the different species of *Gossypium* was presented about a decade later by Skovsted (1933, 1935b). In India, Banerji (1929) reported the chromosome numbers of 28 varieties of Indian cottons belonging to *G. arboreum* and *G. herbaceum* and also four cultivated varieties of American cottons acclimatized in India.

There are five major groups of species with $n=13$ ($2n=26$) chromosomes, such as: (*i*) the wild Australian species (*sturtii* and *robinsonii*); (*ii*) the wild

TABLE 51. CHROMOSOME NUMBER IN THE DIFFERENT SPECIES OF *Gossypium*

Major groups of species	Species	n	2n	Authors
Wild Australian				
I. **Sturtiana:**	*G. sturtii* von Mueller	13	26	Skovsted (1933, 1935b) also as cited by Harland (1932c), Longley (1933), Webber (1934)
	G. robinsonii von Mueller	13	—	Douwes and Cuany (1952)
Wild American				
II. **Erioxyla:**	*G. aridum* (Rose and Standley) comb. nov.	13	26	Skovsted (1933)
	G. armourianum Kearney	—	26	Longley (1933), Skovsted (1933)
	"	13	—	Webber (1934)
	G. harknessii Brandegee	—	26	Longley (1933), Skovsted (1933), Sikka *et al.* (1944)
	"	13	—	Webber (1934)
III. **Klotzschiana:**	*G. klotzschianum* Andersson	—	26	Skovsted (1933)
	"	13	—	Webber (1934)
	G. klotzschianum var. *davidsonii* (*G. davidsonii* Kell.)	13	26	Lans and Longley (cited by Harland, 1929d), Longley (1933), Skovsted (1933, 1935b), Webber (1934), Sikka *et al.* (1944)
	G. raimondii Ulbrich	13	26	Boza Barducci and Madoo (1941)
IV. **Thurberana:**	*G. thurberi* Tod.	—	26	Longley (1929) (cited by Harland, 1939)
	G. trilobum (Moc. *et* Sess *ex* DC.) comb. nov.	13	26	Longley (cited by Skovsted, 1935b), Skovsted (1933)
	G. gossypioides (Ulb.) Standley	13	—	Brown and Menzel (1952b)
Wild African				
V. **Anomala:**	*G. triphyllum* Hoch.	13	—	Douwes and Cuany (1951)
	G. anomalum Wawra *et* Peyr.	—	26	Skovsted (1933), Sikka *et al.* (1944)
Wild Afro-Asian				
VI. **Stocksiana:**	*G. stocksii* Mast.	13	26	Youngman and Pande (1927), Banerji (1929), Skovsted (1933), Davie (1933), Abraham (1940), Jacob (1941a, 1942-43)
	G. areysianum Deflers	13	—	Douwes (1953)
	G. somalense Gurke	13	—	Douwes (1951)
Cultivated Old World				
VII. **Herbacea:**	*G. arboreum* L.	13	26	Nikolajeva (1922-23) (cited by Zaitzev, 1923), Denham (1924), Banerji (1929), Longley (1933), Skovsted (1933), Webber (1934), Mikhailova (1936), Abraham (1940), Jacob (1942-43), Sikka *et al.* (1944)

TABLE 51. CHROMOSOME NUMBER IN THE DIFFERENT SPECIES OF *Gossypium* (*Contd.*)

Major groups of species	Species	n	2n	Authors
	G. herbaceum L.	13	26	Nikolajeva (1922-23, cited by Zaitzev, 1923), Denham (1924), Banerji (1929), Youngman (1931), Nakatomi(1931), Longley (1933), Skovsted (1933), Davie (1933), Webber (1934), Arutjunova (1936), Mikhailova (1936), Abraham (1940), Jacob (1942-43), Sikka *et al.* (1944)
Cultivated New World VIII. **Hirsuta:**	*G. hirsutum* L.	26	52	Nikolajeva(1922-23, cited by Zaitzev, 1923), Denham (1924), Beal (1928), Banerji (1929), Nakatomi (1931), Longley (1933), Skovsted (1933), Davie (1933), Arutjunova (1936), Mikhailova (1936), Webber (1934), Sikka *et al.* (1944)
	G. hirsutum var. *punctatum* (*G. traitense* Parl.)	26	—	Skovsted (1933)
	G. hirsutum var. *punctatum* (*G. purpurascens* Poir.)	26	52	Nikolajeva (1922-23, cited by Zaitzev, 1923), Skovsted (1933)
	G. hirsutum var. *punctatum* (*G. punctatum* Sch. *et* Thon.)	—	52	Nikolajeva (1922-23, cited by Zaitzev, 1923)
	G. barbadense L.	26	52	Nikolajeva (1922-23, cited by Zaitzev, 1923), Denham (1924), Beal (1928), Nakatomi (1931), Longley (1933), Skovsted (1933), Webber (1934), Mikhailova (1936), Sikka *et al.* (1944)
	G. barbadense var. *darwinii* (*G. darwinii* Watt)	26	—	Webber (1934), Skovsted (1933)
Wild Polynesian VIII. **Hirsuta:**	*G. tomentosum* Nutt. *ex* Seem	26	52	Lans (cited by Harland, 1929d), Webber (1934), Skovsted (1933)

Note:— The original name of the species under which the chromosome number was reported is given within brackets in some of the cases entered in the above table. Original names of other species have been listed by Darlington and Janaki Ammal (1945); their synonymy has been given by Hutchinson, Silow and Stephens (1947).

American species (*aridum, armourianum, harknessii, klotzschianum, klotzschianum* var. *davidsonii, raimondii, thurberi, trilobum* and *gossypioides*) ; (*iii*) the wild African species (*triphyllum* and *anomalum*) ; (*iv*) the wild Afro-Asian species of Pakistan (Sind), Arabia and Somaliland (*stocksii, areysianum* and *somalense*); and (*v*) the cultivated species of the Old World (*arboreum* and *herbaceum*).

The cultivated species of the New World have $n=26$ ($2n=52$) chromosomes. These species are *hirsutum* and *barbadense.* The wild species, *tomentosum*, from Hawaii also has $2n=52$ chromosomes.

The cultivated species of the New World ($2n=52$) have been found to have an allopolyploid constitution with a set of 13 chromosomes homologous with the 13-chromosome set of the Old World cottons and another set of 13 chromosomes homologous with that of the 13 chromosomes of the wild American diploid species (Skovsted 1935b, 1937 ; Beasley, 1942).

Size and Morphology of Chromosomes. The morphology of chromosomes in cotton was studied for the first time by Denham (1924). He found that two chromosomes were distinctly larger than the others in *G. barbadense.* Later Beal (1928), working on *barbadense*, observed a uniform gradation in size from very small to relatively large chromosomes with five or six larger than the others. Davie (1933) observed two pairs of chromosomes in cultivated American cottons to be longer than the others as reported by Denham. Baranov (1930), while studying chromosome distinctions in the cultivated Old World species, reported the presence of chromosomes with equal and unequal arms, with or without satellites.

Webber (1935) reported that the somatic chromosomes of *thurberi* are slightly larger than those of the other wild American species. He further observed that the differences in chromosome sizes in cultivated American species are very slight and that there is a gradation of sizes rather than a sharp distinction between large and small chromosomes. A considerable difference in size between the chromosomes of *sturtii* and *davidsonii** was found by Skovsted (1935b), the former possessing larger chromosomes.

On the basis of results obtained in the study of the Old World-New World interspecific hybrids, Skovsted (1933) concluded that the New World cottons are allotetraploids, originating from a cross between two species with morphologically dissimilar and non-homologous sets of chromosomes. The size of the chromosomes seemed to indicate the nature of these two species. Half the complement of chromosomes of New World cottons were found to be small and the other half larger. The size of larger chromosomes was comparable with that of the chromosomes of the cultivated Old World species while the smaller chromosomes were comparable in size with those of the North American species, such as *davidsonii**, *thurberi, harknessii, armourianum* and *aridum*. He, therefore, postulated that one of the 13-chromo-

some genoms is from the cultivated Old World species and the other is probably from the North American diploid species.

Arutjunova (1936) studied in detail the size and morphology of chromosomes in *herbaceum* ($2n=26$) and *hirsutum* ($2n=52$). She states that in *G. herbaceum*, "thirteen chromosomes types were established, seven of which showed secondary differentiations. About one-third of the chromosomes are much smaller than the others. In *G. hirsutum* each type appeared to be present twice, suggesting that the species is of an autopolyploid origin, and not an amphidiploid as stated by Skovsted."

Mikhailova (1936) studied the karyotype in the Old World and New World cottons. She reported that the karyotype of all the Old World cottons was substantially the same. The New World cottons ($2n=52$) contained 26 larger and 26 smaller chromosomes, though no clear difference, as was observed by Skovsted, could be detected. The satellites characteristic of the Old World group were absent in *G. barbadense* and *G. hirsutum*, though they were found in *G. hopi** (*G. hirsutum* race *punctatum*). The variety Navrotskii had two large satellites with a constriction unlike the other members of the species, *G. hirsutum*.

In a subsequent publication Mikhailova (1938) stated that the chromosome morphology of the New World cottons ($2n=52$) agrees approximately but not exactly with Skovsted's hypothesis that they are amphidiploids derived from an Old World cotton and a 13-chromosome wild American species. She also confirmed the findings of Skovsted that the New World cottons possessed 13 larger and thicker and 13 smaller and thinner chromosomes, though she stated that the distinction is not absolute and that the difference in thickness cannot be measured.

Banerji (1929) did not notice any appreciable difference in the size of chromosomes in his study of the 32 varieties of Indian cottons (cultivated Old World species). Only one slightly bigger chromosome was noticed in some cases. According to Baranov (1930) somatic chromosomes of these species exhibit morphological distinctions such as differences in the length of the arms and arms with or without satellites. Later, Skovsted (1933, 1934b) reported that the two species are characterised by 13 pairs of relatively large chromosomes and that 26 somatic chromosomes of *arboreum* are of equal size and four of them possess satellites. After a careful study of *herbaceum*, Arutjunova (1936) divided the somatic complement into 13 types noting that several of the chromosomes types resembled one another and that four of them were much smaller than the others. Denham (1924) and Davie (1933), however, observed that one pair of chromosomes in the cultivated Old World cottons was longer than others. It will be noted that neither Skovsted (1933, 1934b) nor Arutjunova (1936) found the larger pair of chromosomes reported by Denham (1924), Davie (1933) and Webber (1935)

Abraham (1940) studied the morphology of the somatic chromosomes of Koilpatti 1 (*G. arboreum*, Karunganni 1), 2919 (*G. herbaceum*) and *G. stocksii*. He found that the chromosomes of *arboreum* and *stocksii* were almost identical in their frequency distribution for length, which ranged from 2.2 to 2.3 microns. Five metaphase plates of each species gave average chromosome lengths per plate as follows :

	herbaceum	*stocksii*	*arboreum*	C.D. at 5% level
Mean length per plate in microns	78·3	68·4	68·0	1·77

Furthermore, the chromosomes of *stocksii* were found to be thinnest and those of *herbaceum* thickest. In all the three species, two pairs of chromosomes were found to have satellites, as was observed by Skovsted (1933, 1935b) and Arutjunova (1936). These chromosomes were morphologically distinct from each other, one pair having medium attachment constriction, and the other sub-median at the satellite end. Of the remaining chromosomes in each of the three species studied, two pairs have their attachment constrictions situated nearly at a third of their length from one end. In *stocksii* and *arboreum* these two pairs are among the medium sized ones, in *herbaceum* one of these pairs represents the longest among all the pairs. The remaining chromosomes of the three species have more or less median attachment constrictions.

Jacob (1941a, 1942-43) studied the somatic chromosome morphology of seven types belonging to *arboreum*, *herbaceum* and *stocksii*. Chromosomes of all these species could be classified into seven groups depending upon their length and also the positions of their constrictions (Table 52). The basic number of chromosomes was, therefore, inferred to be seven and the Old World cultivated species and *stocksii* were considered to be secondary allotetraploids having the constitution (4b-2; b=basic chromosome number, 7). It was speculated that they evolved by hybridisation of two 7-chromosome types, the nucleolar chromosome being satellited in one and secondarily constricted in the other, followed by chromosome duplication and loss of two chromosomes. On the other hand, the New World diploids were inferred to be secondary autotetraploids in that they have two pairs of morphologically similar satellited chromosomes. From a study of nucleolar chromosomes, the evolutionary trend in *G. arboreum* varieties was inferred as follows: *typicum** (race *indicum*) represents an early stage, *neglectum** (race *bengalense*) a later and *cernuum* (race *cernuum*) a still later, in the evolution

of the species. In *herbaceum*, *typicum** appeared to be more highly evolved than *frutescens**. It was noticed that the longest chromosomes of *G. stocksii* are much longer than those in the other types investigated so far and that there is a wide range between the longest and the shortest chromosome pairs. Among the *arboreums* the longest chromosomes of *typicum** and *cernuum** are nearly equal and the shortest ones of *neglectum** and *cernuum** are equal. The difference between the longest and the shortest chromosome pairs is greatest in *cernuum** and least in *neglectum**. The total length of all the chromosomes is greatest in *typicum** and least in *cernuum**. Among the different *herbaceum* types studied, the shortest chromosomes in them all are nearly equal in size. The satellited as well as secondarily constricted chromosomes of *G. stocksii* appear to be the longest. The shortest satellited chromosomes are in *cernuum**. Among the *herbaceum* types, *frutescens* (*wightianum*) has the longest nucleolar chromosomes; the secondarily constricted chromosomes in *africanum* and *typicum** appear to be morphologically similar in that they have their longest segment in the middle. Again, the secondarily constricted chromosomes in *frutescens* (*wightianum*) appear to be morphologically similar to that of *G. arboreum* vars. *typicum** and *neglectum** in having their longest segment towards the end.

TABLE 52. KARYOTYPES IN OLD WORLD SPECIES (JACOB, 1941a, 1942-43)

Species	Nucleolar chromosomes		Non-nucleolar chromosomes								$2n$
	A	B	C_1	C_2	C_3	C_4	D_1	D_2	D_3	D_4	
G. stocksii	2	2	4	4	4	4	6	0	0	0	26
G. arboreum var. *typicum** (Nadam, Erode)	2	2	8	4	0	0	4	4	2	0	26
G. arboreum var. *typicum** (K. 1)	2	2	2	10	2	0	6	2	0	0	26
G. arboreum var. *neglectum**	2	2	2	6	8	2	4	0	0	0	26
G. arboreum var. *cernuum**	2	2	2	4	6	4	6	0	0	0	26
G. herbaceum var. *africanum*	2	2	4	0	0	0	4	6	6	2	26
G. herbaceum var. *frutescens** (2919)	2	2	4	10	4	2	2	0	0	0	26
G. herbaceum var. *typicum** (2282)	2	2	2	10	6	0	2	2	0	0	26

A=Secondarily constricted chromosomes.

B=Satellited chromosomes.

C_1, C_2, C_3, C_4,=Medianly constricted chromosomes graded according to their length—C_1 the longest and C4 the shortest.

D_1,D_2,D_3,D_4,= Sub-medianly constricted chromosomes, also graded like C_1-C_4; D_1 the longest and D_4 the shortest.

TABLE 53. KARYOTYPES IN THE DIFFERENT VARIETIES OF *Gossypium arboreum* (SIKKA, RAHMAN AND AFZAL, 1944)

Variety	Forma	Types	Karyotypes												Total length of chromosome complement (mm.)	Number and size of nucleoli
			A^+	B^+	C_1	C_2	C_3	C_4	C_5	D_1	D_2	D_3	D_4	D_5		
var. *neglectum**	forma *bengalensis** H. & G.	Rosea VIII	2	2	4	8	—	—	—	2	6	2	—	—	64·6	2 big + 2 small
		Rosea XV	2	2	6	4	—	—	—	2	2	8	—	—	59·2	,, ,,
		Rosea 210	2	2	4	6	—	—	—	2	2	8	—	—	63·7	,, ,,
		Mollisoni 39	2	2	6	—	2	—	—	6	4	4	—	—	61·7	,, ,,
		Sanguineum 119	2 Sat	2	—	8	6	—	—	—	2	4	2	—	56·3	,, ,,
	forma *indica** H. & G.	Gaorani 16C	2 Sat	2	6	2	—	—	—	8	4	2	—	—	67·8	2 big + 2 small
		Gaorani 4M.11	2 Sat	2	—	8	6	—	—	—	2	4	2	—	54·6	4 equal
		Gaorani 6E.3	2 Sat	2	—	—	2	4	4	—	—	—	8	4	46·3	,,
		Gaorani 135	2 Sat	2	—	—	8	2	—	—	—	2	8	2	41·9	,,
		Karunganni 2	2 Sat	2	—	4	6	—	—	—	4	4	4	—	55·8	,,

	forma *burmanica** H. & G.	Chinese Million Dollar	2 Sat	2	—	6	2	—	—	—	2	8	4	—	60·6	2 big + 2 small
		New Million Dollar	2 Sat	2	—	—	—	6	2	—	—	4	8	2	40·8	,, ,,
		Shan	2 Sat	2	—	—	2	2	—	—	—	6	8	4	46·8	,, ,,
var. *typicum**	forma *bengalensis** H. & G.	Intermedium Jethi	2	2	8	4	2	—	—	—	2	6	—	—	63·8	4 almost equal
	forma *indica** H. & G.	Nadam	2 Sat	2	6	4	2	—	—	—	6	4	—	—	60·6	2 big + 2 small
	forma *burmanica** H. & G.	Wagale	2 Sat	2	4	4	—	—	—	6	6	2	—	—	66·2	4 almost equal
var. *cernuum** H. & G.		Comilla	2	2	—	10	2	—	—	2	6	2	—	—	61·4	2 big + 2 small
		026/42	2 Sat	2	—	6	6	2	—	—	2	6	—	—	59·9	,, ,,

+ In the column of chromosome A, 'Sat' means a chromosome with thick-knobbed satellite; chromosome B is always thin satellited.

TABLE 54. KARYOTYPES IN THE DIFFERENT VARIETIES OF *Gossypium herbaceum* (SIKKA, RAHMAN AND AFZAL, 1944)

Variety	Types	Karyotypes																	Total length of chromosome complement (mm.)	Number and size of nucleoli
		A+	B+	C_1	C_2	C_3	C_4	C_5	D_1	D_2	D_3	D_4	D_5	E_1	E_2	E_3	E_4	E_5		
var. *africanum** H. & G.	Africanum	2	2	4	4	4	—	—	2	6	2	—	—	—	—	—	—	—	61·0	2 big + 2 small
var. *frutescens** H. & G.	K. 1	2 Sat	2	—	6	4	—	—	—	—	6	4	—	—	—	—	2	—	54·1	4 almost equal
	Jayawant	2 Sat	2	—	—	—	4	2	—	—	4	10	—	—	—	—	2	—	43·8	2 big + 2 small
var. *typicum** H. & G.	Russian	2 Sat	4	—	—	2	—	—	—	—	6	6	—	—	—	4	2	—	49·5	2 big + 2 small + 2 medium
	Russian 20	2 Sat	4	—	—	—	4	—	—	—	2	8	—	—	—	4	2	—	42·9	,, ,,
	Persian 210	2 Sat	2	—	—	—	6	—	—	—	—	6	4	—	—	4	—	2	38·4	2 big + 2 small

+ In the column of chromosome A, 'Sat' means a chromosome with thick-knobbed satellite; chromosome B is always thin satellited.

It will be noticed that the results of Jacob (1941a; 1942-43) differed considerably from Abraham's (1940) with regard to relative size of the chromosomes and observations on the satellited pair in Old World cottons. Abraham reported two pairs of satellited chromosomes while Jacob observed only one satellited pair and one pair showing a thick secondary constriction. Jacob (1942-43) pointed out that the chromosomes of all the types could be classified into seven groups each, depending upon their length and morphology. The results of Jacob, on chromosome morphology in Old World cottons, thus differ from those reported by Skovsted (1935b), Arutjunova (1936) and Abraham (1940).

Jacob (1941b) also reported certain chromosome abnormalities in the root tips of Old World cottons ; for example, the occurrence of ring chromosomes in *G. herbaceum* var. *africanum** and lateral satellites in *G. arboreum* var. *typicum* forma *indica**.

Sikka, Rahman and Afzal (1944) studied in detail the morphology of the somatic chromosomes of 24 types belonging to cultivated varieties representing different taxonomic groups of *G. arboreum* and *G. herbaceum*, two cultivated American types (*hirsutum*) and three wild species, viz., *G. anomalum*, *G. davidsonii** and *G. harknessii.* Besides recording chromosome numbers, they observed: (*i*) the position of primary constriction in each chromosome; (*ii*) the length of chromosomes; (*iii*) the number of satellited and secondarily constricted chromosomes; and (*iv*) the number of nucleoli organised at telophase. Their observations, summarized in Tables 53 and 54 indicate that all the diploid varieties except the wild species and two Russian varieties of *G. herbaceum* (Russian 25 and Russian 20) in which six satellites and six nucleoli were seen, showed two pairs of nucleolar chromosomes which is indicative of their allotetraploid nature.

In the Punjab-American cottons (*hirsutum*), the above authors observed that the varieties, L. S. S. and 289F/43, have only six nucleolar chromosomes in their somatic complement and it appears that they have lost some nucleolar organisers during the course of evolution. The complement of nuceolar chromosomes in some cultivated Old World species consists of one chromosome pair with secondary constrictions and another with satellites, as reported by Jacob (1941a, b), while in others both pairs of nucleolar chromosomes are clearly satellited, though one of them possesses slightly thicker satellitic knobs. In *arboreum* the general morphology of nucleolar chromosomes of the *sanguineum** cotton of the Punjab bears greater resemblance to that of Karunganni and Gaorani cottons (*indicum*) than to the Roseum (*bengalense*) types. The nucleolar chromosomes of Comilla (*cernuum*) bear a greater similarity with those occurring in forma *bengalensis** of *G. arboreum*, one pair having thick secondary constrictions and the other having thin satellites. Comillas may, therefore, not belong to *cernuum** which has two pairs of well differentiated satellites. In the case of *herbaceum* the presence

of secondary constrictions in the primitive *africanum** and their transition into progressively thin satellites in the highly evolved races, *frutescens** (*wightianum*) and *typicum**, suggests that the satellite is a higher evolutionary type than the secondary constriction. A clear shortening of the chromosomes, besides a greater tendency towards the attainment of subterminal primary constrictions with advance in evolution, was observed in the varieties grouped under *G. herbaceum.*

The somatic complement of *G. hirsutum*, according to Sikka *et al.* (*loc. cit.*) could be clearly divided into two groups, one consisting of thick chromosomes, such as occur in the cultivated Old World species, and the other comprising thin chromosomes of the type found in the wild American diploids. This observation is in conformity with that of Skovsted (1933) and could be correlated with the allopolyploid nature of *G. hirsutum*. The length and morphology of chromosomes of the *arboreum* types classified within the same group have shown wide variation, but the structure of nucleolar chromosomes within the same group is constant and bears greater association with the geographical distribution than with the branching habit of the different types. It, therefore, seems more appropriate to assign varietal status on the basis of geographical distribution than on that of growth and branching habit as has been done by Hutchinson and Ghose (1937b). The contemporaneous studies of Silow (1944a) on the genetics of species development in the Old World cottons support this inference. He has suggested that no formal taxonomic sub-division of *arboreum* be made on the basis of branching habit and that geographical races represent the best natural sub-division.

The idiogrammatic chromosome formulae of the three wild species as reported by Sikka, Rahman and Afzal (1944), are as follows :

G. anomalum $2A + 4B + 2C_3 + 4C_4 + 6D_3 + 2D_5$
*G. davidsonii** $2A + 4B + 2C_3 + 6C_4 + 2C_5 + 4D_3 + 6D_4$
G. harknessii $2A + 4B + 4C_3 + 4C_4 + 6C_5 + 2D_3 + 4D_4$

The chromosomes of these three wild species were shorter than most of the cultivated Old World diploids ; the average length of the somatic complement being 43·3 microns in *anomalum*, 42·4 microns in *davidsonii**, and 40·4 microns in *harknessii*. Besides this difference, the chromosomes of these wild species were also thinner than those of the cultivated 13-chromosome species. All these three wild species had six nucleolar chromosomes, out of which one pair bears a thick secondary constriction and the other two pairs possess fine satellites at their proximal arms. Corresponding to these three pairs of chromosomes, six nucleoli, among which three distinct sizes could be discerned, were organised at early telophase.

CYTOLOGY OF INTERSPECIFIC HYBRIDS

The cytology of interspecific hybrids of various combinations has been studied extensively by several workers (Feng, 1935 ; Skovsted, 1934a, b,

1935a, c, 1937; Webber, 1935, 1939; Beasley, 1940a, 1942; Boza Barducci and Madoo, 1941; Iyengar, 1943, 1944a, b, 1945; Afzal, Sikka and Rahman, 1945; Stephens, 1945; Deodikar, 1949, 1950; Brown and Menzel, 1950, 1952a, b, c, d; Douwes, 1951, 1953; Gerstel, 1953a; Menzel, 1955; Menzel and Brown, 1955; Gerstel and Sarvella, 1956). According to Stephens (1947b) cytogenetic evidence points out that the genus *Gossypium* is monophyletic, as nearly all the possible combinations of interspecific crosses can be made artificially, some very readily, others with great difficulty, sometimes involving *in vitro* culture of immature hybrid seed (Beasley, 1940a; Skovsted, 1935a). The hybrids obtained exhibit a wide range of fertility from fully fertile to completely sterile hybrids depending upon the parental species employed. Even in the completely sterile hybrids there is often a fair amount of pairing between chromosomes at meiosis (Abraham, 1940; Beasley, 1942; Feng, 1935; Skovsted, 1934a, b, 1937; Webber, 1935, 1939). However, according to Brown and Menzel (1952a, b, c, d), attempts to obtain hybrids between certain species by direct crossing have failed hence their cytological homology has been studied either indirectly by comparing the behaviour of each in hybrids with a third species which is compatible with both or directly in induced hexaploid hybrid combinations.

Brown (1954) has reported that pachytene pairing in sterile as well as fertile species hybrids appears to be as intimate as within species. She has, therefore, concluded that pachytene pairing in hybrids cannot be considered a measure of chromosome or species differentiation and thus metaphase pairing continues to be the best criterion of chromsome homology. It is the chiasma formation and not the pachytene association of chromosomes that appears to be very important for determining the chromosome homologies in species hybrids.

The various combinations of interspecific hybrids may be grouped as follows.

Those between—

1. The different diploid species of the Old World.
2. The Old World diploid species and the New World diploid species.
3. The different diploid species of the New World.
4. The different tetraploid New World species.
5. The New World tetraploid species and the Old World diploid species.
6. The New World tetraploid species and the New World diploid species.

HYBRIDS BETWEEN OLD WORLD DIPLOID SPECIES

The interspecific hybrid between the two cultivated Old World cottons is usually fertile. Webber (1935) reported regular meiosis following formation

of 13 bivalents in the hybrids involving *G. arboreum* vars. *sanguineum** and *cernuum** on the one hand and *G. africanum** and *G. herbaceum* on the other; occasionally 2 univalents and 12 bivalents were also observed. In *herbaceum* x *cernuum* average 0·2I+12·9II per cell were reported by Webber (1939). There was a considerable reduction in chiasma frequency (Skovsted, 1933). Beasley (1942), Gerstel (1953a) and Gerstel and Sarvella (1956) have reported that *arboreum-herbaceum* hybrids show a reciprocal translocation ring of four chromosomes at metaphase during meiosis. The average values of metaphase I configurations per cell in *herbaceum-arboreum* hybrids computed from Gerstel's (1953a) data are 0·2I+11·16II+0·04III+0·84IV. All the representatives, excepting one, of the different geographical races of *arboreum* carry the same chromosomal arrangement and differ from *herbaceum* by one major segmental interchange (Gerstel and Sarvella, 1956). The exceptional *arboreum*, Karhadi 11a, is a selection for wilt resistance made in Gujerat where Rozi (*arboreum*) and Goghari (*herbaceum*) cottons were grown mixed. In hybrids with *herbaceum* it showed regular 13 bivalents during meiosis. This was inferred to be due to introgression from the latter species, morphological manifestation of which was given by the reflexed bracteoles and round bolls. Inversion heterozygosity between these two species was recorded by Beasley (1942).

The cytology of the interspecific hybrids between the cultivated Old World cottons and the wild species, *G. stocksii*, has been investigated ; the results are summarised in Table 55.

Abraham (1940) studied the cytology of K.1 (Karunganni 1) cotton (*G. arboreum* var. *neglectum* forma *indica* H. & G.)* and *G. stocksii* and their hybrids. The first and second meiotic divisions in the parents were quite normal. The mean chiasmata frequency per bivalent at diplotene was nearly 1·7 in both. Although the reduction of the mean number of chiasmata per bivalent due to terminalization was only slight between the diplotene and diakinesis phases (0·03 in *arboreum* and nil in *stocksii*), it was of considerable order between diakinesis and metaphase (0·08 in *arboreum* and 0·10 in *stocksii*). In the F_1 the chromosome pairing was incomplete, the number of bivalents in the nucleus varying from 5 to 9 with an average of 7·13. The mean chiasmata per bivalent at diplotene was only 1·3 and the reduction of mean chiasmata per bivalent due to terminalization and development of the first division spindle in the hybrid were highly irregular. Sterility of hybrid was due to irregularities of cell division caused by incomplete pairing of chromosomes at meiosis. In all crosses between *G. stocksii* and other Old World cottons, not more than seven chromosomes of two species were found to be homologous, suggesting thereby that the remaining six chromosomes of *G. stocksii* had a different origin.

The interspecific hybrids between the Old World cultivated cottons and the wild species, *G. anomalum* have been studied and the results have been

TABLE 55. CHROMOSOME BEHAVIOUR OF THE F_1 HYBRIDS INVOLVING THE OLD WORLD WILD AND CULTIVATED COTTON SPECIES

Hybrids	Chromosome behaviour at Metaphase I				Chiasmata per bivalent	Author
	I	II	III	IV		
1. *stocksii* with:						
(i) *arboreum* var. *neglectum* forma *indica**	11·74	7·13			1·3	Abraham, 1940
(ii) *arboreum* var. *nanking**	17·3	4·4			1·07	Skovsted, 1937
(iii) *sanguineum**	24·1	0·95				Webber, 1939
(iv) *arboreum*	13·5	6·2			1·11	Skovsted, 1937
(v) ,,	18·4	3·8				Beasley, 1942
(vi) *herbaceum* var. *wightianum**	19·6	3·2			1·05	Skovsted, 1937
2. *anomalum* with:						
(i) *arboreum*	3·1	10·5	0·2	0·4	1·37	Skovsted, 1937; Beasley and Richmond, 1939
(ii) *arboreum* var. *nanking**	1·7	11·7	0·2	0·1	1·48	Skovsted, 1937
(iii) *arboreum* var. *typicum* (*sanguineum*)*	2·4	11·8				Webber, 1939
(iv) ,, ,,	6·0	10·0				Afzal, Sikka and Rahman, 1945
(v) *arboreum* (*sanguineum*)	1·61 +	10·61 +	0·23 +	0·61 +	1·31	Gerstel, 1953a
(vi) *arboreum* var. *neglectum* forma *bengalensis**	2·6	11·7				Afzal, Sikka and Rahman, 1945
(vii) *arboreum* var. *neglectum* forma *indica**	7·8	9·1				,,
(viii) *arboreum* (*Nandyal 14*)	3·8 +	9·95 +	0·23 +	0·52 +	1·31	Gerstel, 1953a
(ix) *herbaceum* race *wightianum*	1·5 +	12·25 +			1·28	,,
(x) *herbaceum* race *kuljianum*	2·4 +	11·7 +	0·02 +		1·28	,,
(xi) *herbaceum* var. *africanum**	2·5	11·8		1·41	1·41	Skovsted, 1937
3. *sturtii* with:						
(i) *arboreum*	2·8	9·8	0·6	0·4	1·32	,,
(ii) *herbaceum*	21·6	2·2				Webber, 1939

Note: The average of I to IV marked with the sign of + do not appear in the original papers; they have been calculated from the given data.

presented in Table 55. Afzal, Sikka and Rahman (1945) recorded that the chromosome conjugations at metaphase I in the F_1s of three varieties, viz., Red *arboreum*, K.1 (Karunganni 1) and Jubilee (all belonging to *G. arboreum*) with the wild species *G. anomalum* were variable. Due to the anomalous behaviour of univalents and the formation of single and double chromatin bridges both during heterotypic and homotypic divisions, the distribution of the chromatin material to daughter nuclei was unequal and as such all three hybrids studied by these workers were mostly sterile.

Most of the seeds set were non-viable but a few of them germinated and showed only 26 chromosomes in their somatic cells.

Gerstel (1953a) observed that *anomalum-herbaceum* hybrids produce no ring configurations of four chromosomes while *anomalum-arboreum* hybrids do, which strengthens the view point (Hutchinson, 1954) that *herbaceum* is more primitive of the cultivated Old World species.

The chromosomal behaviour of the hybrids involving Old World cultivated species on the one hand and *G. sturtii* (wild Australian species) on the other has also been studied ; the findings are summarised in Table 55.

F_1 (*sturtii* x *robinsonii*) showed almost complete chromosome pairing (Douwes and Cauny, 1953). Meiotic behaviour in some more interspecific hybrid combinations among the Afro-Asian species of *Gossypium* has been studied by Douwes (1951, 1953). The findings on first metaphase configurations are summarised in Table 56.

TABLE 56. CHROMOSOME BEHAVIOUR IN THE F_1 HYBRIDS INVOLVING THE WILD OLD WORLD COTTON SPECIES

Hybrids	Metaphase I configurations (Mean No. per PMC)		Author
	I	II	
anomalum (♀) with:			
(*i*) *triphyllum*	0·06	12·96	Douwes (1953)
(*ii*) *stocksii*	20·7	2·7	Douwes (1951)
(*iii*) *somalense*	23·4	1·3	,,
areysianum (♂) with:			
(*i*) *anomalum*	23·1	1·5	Douwes (1953)
(*ii*) *stocksii*	1·6	12·2	Douwes (1953)
(*iii*) *somalense*	0·2	12·9	Douwes (1953)
somalense x *stocksii*	0·7	12·7	Douwes (1951)

HYBRIDS BETWEEN OLD WORLD AND NEW WORLD DIPLOID SPECIES

The findings on meiotic behaviour of such hybrids are presented in Table 57.

In *davidsonii-sturtii* hybrid, Skovsted (1935c) reported inter-genomal pairing about nine times more than intra-genomal pairing.

Crosses of *G. gossypioides* with *herbaceum*, *arboreum* and *anomalum* gave hybrids which survived for about two to four months only (Brown and Menzel, 1952b, c).

HYBRIDS BETWEEN NEW WORLD DIPLOID SPECIES

These diploid species themselves show 13 bivalents during meiosis ; secondary association was also noticed which indicated that the basic number of chromosomes in them is 6 (Skovsted, 1937). Chromosome behaviour in the interspecific hybrids obtained by inter-crossing them is summarised in

TABLE 57. CHROMOSOME BEHAVIOUR OF THE F$_1$ HYBRIDS INVOLVING THE DIPLOID SPECIES OF THE NEW WORLD AND OLD WORLD

Hybrids		Chromosomal associations at MI I	II	III	IV	Chiasma frequency per bivalent	Author
1. *arboreum* with :							
thurberi		9·6	7·8	0·2	0·05	1·16	Skovsted, 1937
*nanking** with :							
thurberi		24·0	1·0				Webber, 1939
2. *anomalum* with :							
aridum		21·15	2·35	0·05		1·03	Skovsted, 1937
*davidsonii**		19·9	3·05			1·08	Skovsted, 1937
,,		25·6	0·2				Webber, 1939
,,		18·4	3·8				Beasley, 1942
,,		17·6	4·2				Brown, 1951
thurberi		14·3	5·7	0·01		1·12	Skovsted, 1937
3. *sturtii* (♀) with:							
armourianum		8·5	8·2	0·3	0·1		,,
,,	(Mostly)	26					Webber, 1935
	(Range)	14–26	0–6				Webber, 1935
	(Average)	24·1	1·0				Webber, 1935
harknessii							Webber, 1935
	(Mostly)	26					Webber, 1935
	(Range)	18–26	0–4				Webber, 1935
	(Average)	24·6	0·7				Webber, 1935
4. *sturtii* (♂) with:							
*davidsonii**		24·0	1·0				,,
,,	(Mostly)	26					Skovsted, 1935c
	(Range)	16–26	0–5				Skovsted, 1935c
	(Average)	14·9	5·3	0·1	0.03	1·06	Skovsted, 1935c
(*Thurberia thespesioides**)							
thurberi		26					Webber, 1935
,,		24·5	0·7				Webber, 1939

TABEE 58. CHROMOSOME BEHAVIOUR IN THE F$_1$ HYBRIDS INVOLVING VARIOUS COMBINATIONS OF WILD SPECIES OF THE NEW WORLD

Hybrids	Chromosomal conjugation I	II	Chiasma frequency per bivalent	Author
harknessii x *armourianum*		13	—	Webber, 1935
armourianum x *aridum*		13	—	Skovsted, 1937
*davidsonii** x *klotzschianum*	0·1	12·95	—	Webber, 1939
armourianum x *thurberi* sometimes	2	13	1·57	Skovsted, 1937
armourianum x *thurberi*	0·6	12·7	—	Webber, 1939
harknessii x *thurberi*	0·8	12·6	—	,,
thurberi x *aridum*	0·1	12·95	1·73	Skovsted, 1937
thurberi x *raimondii*	0·2	12·90	—	Boza Barducci and Madoo, 1941
raimondii x *gossypioides*	1·14	12·43	1·67	Brown and Menzel, 1952b, c; Menzel and Brown, 1955

Table 58. The data indicate that New World diploid species have a slight amount of structural differentiation among their chromosomes.

Crosses of *gossypioides* with *harknessii*, *klotzschianum*, *klotzschianum* var. *davidsonii*, and *thurberi* either failed or the hybrids died in the cotyledon stage (Brown and Menzel, 1952b,c).

HYBRIDS BETWEEN NEW WORLD TETRAPLOID SPECIES

All the naturally occurring diploid species of cotton invariably show regular meiosis with 13 bivalents at first metaphase. With the tetraploid species it is not so, although mostly 26 bivalents are observed at first metaphase in meiosis. One association of four and zero to four univalents have been observed in *hirsutum* in not more than 14 per cent. of the pollen mother cells (Webber, 1934, 1938 ; Iyengar, 1947). On the contrary, Menzel and Brown (1954) emphasize that in pure *hirsutum* no convincing cases of multivalents have been seen among several thousand pollen mother cells examined each year.

The three tetraploid species *hirsutum*, *barbadense* and *tomentosum*, as judged by the records available to date, form mostly 26 bivalents in their hybrids (Webber, 1935, 1939 ; Skovsted, 1937). Quadrivalents in their hybrids are more frequent than in the parental pure species (Webber, 1934, 1938 ; Beasley, 1942). Webber (1935) noticed occasional quadrivalents in F_1 hybrids of crosses within the cultivated New World cottons: *hirsutum*, *punctatum**, *barbadense*, *contextum** and *schottii**. He also reported smaller number of chiasmata per cell in these hybrids. Patel, Thakar and Deodikar (1947) have reported occasional quadrivalents in the hybrids of *tomentosum* with the other tetraploid species. More critical information on the meiosis of interspecific hybrids in **Hirsuta** has been supplied recently by Gerstel and Sarvella (1956). They observe that *hirsutum-barbadense* hybrids have been studied by several workers cytologically. Most of the varieties of *barbadense* from the U.S.A. used in these crosses are not reliable indicators of chromosomal arrangement since they may be suspected of introgression from Upland (*hirsutum*). One of the varieties of *barbadense* used by the authors in similar hybrids is presumably *hirsutum* free. Extreme rarity of quadrivalent formation in its hybrids with both *hirsutum* and *tomentosum* shows that all the three species are alike with respect to the structural combinations of the chromosomes. The rare quadrivalent could be due to short inter-chromosomal exchanges differentiating the species and permitting the formation of an occasional chiasma in hybrids. The second possibility should be considered that the factors which control strictly preferential pairing between homologous in an alloploid species are upset in interspecific hybrids thus permitting an occasional chiasma to form between homologous segments of chromosomes belonging to different genoms. As a third possibility one cannot discount at the present time that evolutional changes which occurred in the chromo-

somes to make possible preferential associations proceeded in opposite directions in the different $4x$ species such that segments of the A chromosome of *hirsutum* have retained a closer affinity to segments of the D homologue of *barbadense* than to the A homologue of the latter species. The frequencies of metaphase association between such segments would depend on their length.

They also observe that the occurrence of 25 or 26 closed ring bivalents in **Hirsuta** hybrids represents positive evidence that translocations of entire arms are absent. A case against the presence of interchanges of terminal segments could hardly be made by this method where interstitial chiasmata occur in most cells ; obviously interstitial chiasmata could be located proximally of the points of interchange. In the absence of observed interstitial chiasmata (that is, if all ring bivalents with all terminal chiasmata are present), the argument against translocations would be based on the assumption that terminalisation of chiasmata in interstitial segments beyond points of interchange does not occur ; this has been asserted to be the case by Darlington (1937) but has been disputed by Gottschalk (1954).

HYBRIDS BETWEEN NEW WORLD TETRAPLOID AND OLD WORLD DIPLOID SPECIES

Hybrids between the Old World and New World cultivated cottons have been studied by a number of workers (Zhubrin, 1930; Baranov, 1930; Baranov and Kanash, 1936; Kanash, 1936a,b; Nakatomi, 1931; Skovsted, 1934a,b; Webber, 1935; Feng, 1935; Amin, 1941 ; Iyengar, 1942, 1943, 1944b, 1945 ; Gerstel, 1953a). Most of the workers usually noted the occurrence of 13 to 15 univalents and 12 to 13 bivalents with total chromosome number as 39. Skovsted's results are a bit different in as much as he states that the higher associations were common. In a natural hybrid between the Old World and New World cultivated cottons, Webber (1935) observed usually $13_{II} + 13_{I}$; pairing as low as $9_{II} + 21_{I}$ was observed and as many as four rings of four chromosomes each were sometimes formed. In discussing the bearing of these findings on phylogeny it was suggested that the occurrence of quadrivalents in such hybrids confirms the suggestion that the basic number 13 has arisen by modified tetraploidy. Recently, Gerstel (1953a) and Gerstel and Sarvella (1956) have reported that *hirsutum* gives, during meiosis, two figures of four chromosomes in crosses with *herbaceum* and that *hirsutum* and *barbadense* give a figure of four and a figure of six in hybrids with *arboreum*. The behaviour of *barbadense-arboreum* hybrids as given by Gerstel and Sarvella (1956) is in substantial agreement with that of similar one studied by Skovsted (1934a,b). In the *barbadense-herbaceum* hybrid, Beasley (1942) reported two quadrivalents in each of the four out of eight pollen mother cells studied by him. This is similar to the observations recorded by Gerstel (1953a) for *hirsutum-herbaceum* hybrids. Beasley (1942), however, also observed a hexavalent in one cell which was unexpected according to

Gerstel's (1953a) interpretations. Findings of the various workers on the meiotic behaviour of these hybrids are summarised in Table 59.

TABLE 59. CHROMOSOME BEHAVIOUR IN THE F_1 HYBRIDS BETWEEN NEW WORLD TETRAPLOID SPECIES AND OLD WORLD DIPLOID CULTIVATED SPECIES

Hybrids	Chromosomal conjugation at M I						Author
	I	II	III	IV	V	VI	
hirsutum-herbaceum	12·6	9·9	0·07	1·4	0·07		Beasley, 1942+
,,	12·8	8·82	0·17	2·0	0·02		Gerstel, 1953a+
barbadense-herbaceum	13·1	10·1	0·13	1·13		0·13	Beasley, 1942+
*hirsutum-cernuum**	13·2	12·7	0·1				Webber, 1939
hirsutum-arboreum	13·06	8·6	0·06	0·92	0·04	0·94	Gerstel, 1953a+
barbadense-arboreum	14·4	8·4	1·0	0·6	0·3	0·1	Skovsted, 1934a, b
,,	12·7	8·3	0·09	0·9		1·0	Gerstel and Sarvella, 1956+

+ Average values of the metaphase configurations have been computed from the data provided by the respective authors.

Skovsted (1934b) usually observed $2n=39$ chromosomes in the crosses of the tetraploid with the diploid cultivated cottons, but in one case he reported $2n=52$ chromosomes where a dipilod egg from the Old World cultivated cotton got fertilized by pollen from the New World tetraploid species. In India, chromosome numbers of similar hybrids made at Surat were determined at the Institute of Plant Industry, Indore, by Amin (1941). They possessed $2n=39$ chromosomes invariably. These triploid hybrids proved to be self-sterile.

The findings on first metaphase configurations in the F_1 hybrids of the New World tetraploid species with the Old World wild diploid species are presented in Table 60.

HYBRIDS BETWEEN NEW WORLD TETRAPLOID AND DIPLOID SPECIES

The findings reported on the meiotic behaviour of these hybrids are summarised in Table 61.

Beasley (1942) observed 'bridges' at anaphase of *hirsutum-thurberi* triploid hybrids which was considered to be an evidence of structural differentiation between D chromosomes. According to Gerstel (1956), however, the observed 'bridges' may have been attenuation caused by phenomena other than inversion cross-overs.

INTER-RELATIONSHIPS AND GENOMIC CONSTITUTION OF DIFFERENT *GOSSYPIUM* SPECIES

The cytological study of various combinations of interspecific hybrids has revealed the inter-relationships and genomic constitution of different

TABLE 60. CHROMOSOME BEHAVIOUR IN THE F_1 HYBRIDS OF NEW WORLD TETRAPLOID SPECIES WITH OLD WORLD WILD DIPLOID SPECIES

Hybrids	Chromosomal conjugation I	II	III	IV	Chiasma frequency per bivalent	Author
hirsutum x *sturtii*	20·95	7·6	0·95			Skovsted, 1937
,, ,,	37·9	0·5				Webber, 1939
,, ,,	34·0	2·5				Patel, Thakar and Deodikar, 1947
*purpurascens** x *sturtii*	24·3	6·0	0·8	0·05	1·05	Skovsted, 1937
*punctatum** x *sturtii*	23·95	6·35	0·65	0·1		,,
hirsutum x *anomalum*	18·0	10·5				Webber, 1939
,, ,,	22·7	5·2	0·17			Iyengar, 1944b
barbadense x *sturtii*	32·5	3·1	0·1			Skovsted, 1937
,, (Mostly)	39·0					Webber, 1935
(Range)	31-39	0–4				
(Average)	37·2	0·9				
*darwinii** x *sturtii*	27·1	5·25	0·4	0·05	1·02	Skovsted, 1937
barbadense x *anomalum*	25·4	6·4	0·2	0·05		Iyengar, 1944b
,, ,,	33·8	2·6			1·05	Skovsted, 1937
,, ,,	21·2	8·9				Webber, 1939
(*barbadense* x *schottii**)-*anomalum*	18·1	10·3	0·1			,,
(*contextum** x *hopi**)-*anomalum*	17·8	10·5	0·1			,,
barbadense x *stocksii*	37·9	0·6			1·0	Skovsted, 1937

TABLE 61. CHROMOSOME BEHAVIOUR OF THE F_1 HYBRIDS BETWEEN TETRAPLOID AND DIPLOID NEW WORLD SPECIES

Hybrids	Chromosomal conjugation I	II	III	IV	Chiasma frequency per bivalent	Author
hirsutum x *armourianum*	13	13				Webber, 1934
,, (Mostly)	13	13				Webber, 1935
(4 cells)	13	11		1		
(1 cell)	13	9		2		
hirsutum x *armourianum*	13·5	12·15	0·4			Skovsted, 1937
,, ,,	11·8	13·4	0·2			,,
*purpurascens** x *armourianum*	13·8	12·4	0·04		1·49	,,
*taitense** x *armourianum*	14·5	12·1	0·1		1·55	,,
hirsutum x *aridum*	13·15	12·4	0 35			,,
*purpurascens** x *aridum*	13·0	12·0	0 6	0·05	1·64	,,
hirsutum x *raimondii*	12·57	11·65	0·87	0·125		Boza Barducci and Madoo, 1941
hirsutum x *thurberi*	13·06	12·7	0·18			Webber, 1939
,, ,,	13·5	12·45	0·2		1·54	Skovsted, 1937
*taitense** x *thurberi*	13·4	12·05	0·5			,,
hirsutum x *gossypioides*	15·15	11·23	0·46			Brown and Menezl, 1952b, c
barbadense x *armourianum*	14·75	12·05	0·05			Skovsted, 1937
*darwinii** x *armourianum*	13·2	12·0	0·6			,,
*contextum** x *armourianum*	13·0	12·7	0·1			Webber, 1935
barbadense x *aridum*	13·99	12·28	0·15		1·73	Skovsted, 1937
barbadense x *harknessii*	13·0	13·0				Webber, 1935
barbadense x *thurberi*	12·7	12·4	0·5			Skovsted, 1937
,, ,,	13·27	12·67	0·13			Iyengar, 1944b
barbadense x *gossypioides*	30·13	4·39	0·03			Menzel and Brown, 1955

species of the genus *Gossypium*. On the basis of such studies, Skovsted (1935, 1937) classified the different species under the following six groups :

Group 1: 13-chromosome Asiatic-African species
1. *G. arboreum* and *G. herbaceum*
2. *G. anomalum*

Group 2: 13-chromosome Asiatic species
1. *G. stocksii*

Group 3: 13-chromosome Australian species
1. *G. sturtii*

Group 4: 13-chromosome American species
1. *G. davidsonii* Kell.*
2. *G. klotzschianum* Andss.

Group 5: 13-chromosome American species
1. *G. thurberi*
2. *G. armourianum*
3. *G. harknessii*
4. *G. aridum*

Group 6: 26-chromosome American and Polynesian species
1. *G. tomentosum*
2. *G. darwinii**
3. *G. barbadense*
4. *G. hirsutum*
5. *G. purpurascens** and *G. punctatum**
6. *G. taitense**

It has been shown that the wild African species, *anomalum*, is cytologically close to the cultivated Old World cottons. The species *G. stocksii* is further removed from the latter, as the pairing of the chromosomes in hybrids indicates great cytological divergence. The Australian wild species, *G. sturtii*, is apparently far removed from all other species in the genus, both cytologically and genetically. The species under Groups 4 and 5 appear to form two well marked sections, with each member similar in genetical and cytological affinities to the New World allopolyploids. The species under Group 6 form a separate section with 26 chromosomes and they are of an allopolyploid constitution with a set of 13 chromosomes homologous with the 13-chromosome set of the Old World cottons and another set of 13 chromosomes homologous with that of 13 chromosomes in the wild American diploid species (Skovsted, 1934b, 1935a, 1937).

Skovsted (1935a) stated that *trilobum* and *aridum* often assigned (in early times) to the genera *Thurberia* and *Erioxylum*, respectively, should, on cytogenetic grounds, be classified in the genus *Gossypium*. He also suggested, in this connection, a careful cytogenetical study of the relationship of other genera closely allied to *Gossypium*. His remark applied especially to *Shantzia* $n{=}13$) and to *G. gossypioides* and *G. triphyllum* often referred to as *Selera*

gossypioides Ulb. and *Cienfugosia triphylla* (Harv.) Hochr., respectively, in old literature. As regards *davidsonii* he thought that the species was more closely related to *sturtii* than to any other species.

The cytological studies carried out by Skovsted (1937) and Webber (1939) have clearly indicated that the wild lintless species have $n=13$ chromosomes, but the complement is extensively differentiated so that the species of each continent have a characteristic genom, and pairing in hybrids between species from different continents is low.

Later, Beasley (1942) devised a nomenclature for the various distinct genoms depending upon the crossability among different species. He divided the diploid species into five clear-cut genom classes. He assigned B to the genom of *anomalum*, C to *sturtii*, D to the American wild species, and E to *G. stocksii*. The genoms C and D are widely distinct from the genom B and from each other. No cytological differentiation could be detected within each class but all hybrids between numbers of different classes showed evidence of gross structural differences at meiosis. Four of his classes are sub-divisions of Skovsted's Old World group while D genom class is equivalent to Skovsted's American diploid group.

The genoms B and C fail to cross in all cases. B x D and C x D can be made in some cases. The genom E of *stocksii* is cytologically widely distinct from B, C and D. The successful cross combinations have been studied cytologically ; findings have already been summarised in Tables 55 to 61.

The cultivated Old World species (*arboreum* and *herbaceum*) were assigned A genom (Beasley, 1942) as they are cytologically intercompatible. The cultivated New World species (*hirsutum* and *barbadense*) and the wild species of Hawaii, *G. tomentosum* have AD genoms with one 13-chromosome set homologous with the A genom of the cultivated Old World cottons and another 13-chromosome set homologous with the D genom of the wild diploid New World species. When AD is crossed with either A or D species, the hybrids usually show 13_{II} and 13_{I}. The pairing between the chromosome complements of the New World cottons (AD) and those of *G. stocksii* (E) or *G. anomalum* (B) is very low.

The Old World cultivated species with the A genom and the wild diploid New World species with the D genom constitute the probable ancestors of the allotetraploid New World species. It is difficult to say at present, which particular species are the progenitors of a particular tetraploid species. On the basis of the extent of multiple chromosomal associations during meiosis of the hybrids of *hirsutum* with *herbaceum* and *arboreum*, Gerstel (1953a) suggests that *herbaceum* is closer to the tetraploid cottons than *arboreum*. The results of Harland (1940) and Beasley (1942), on the hexaploids involving four American diploid species, viz., *armourianum*, *aridum*, *thurberi* and *harknessii* all of which were more fertile than the *G. hirsutum* x *herbaceum* hexaploid, indicated clearly that the homologies of the D sets of the wild American

species with the corresponding New World chromosomes were lower than are the A homologies. A hexaploid hybrid between *barbadense* x *raimondii*, which is practically sterile, has shown that the homology of the D_5 genom of *raimondii* with chromosomes of the New World cottons is much closer than is that of the D sets of the other four species mentioned previously (Hutchinson, Silow and Stephens, 1947). On cytological and morphological grounds and in phenogenetic behaviour, *G. raimondii* seems to be a probable ancestor of the cultivated American cottons, contributing the D genom chromosomes. According to Stephens (1947b), "Although the evidence at present available suggests that the *raimondii* genom is most nearly akin to the New World D sub-genom, strictly comparable data have not yet been obtained, it being well known that chromosome conjugation in similar material may vary under different experimental conditions. The recent study of genetic segregation in new allopolyploids of *Gossypium* (6*x* New World—*raimondii* and 6*x* New World—*thurberi*) by Gerstel (1956) has shown that the narrower segregation ratio in 6*x* New World—*raimondii* as compared with 6*x* New World—*thurberi* may be indicative of a closer taxonomic relationship between the New World cottons and *G. raimondii* than between the former and *G. thurberi*. It, however, remains to be proved experimentally that a tetraploid synthesized from a hybrid between an Old World cotton and *G. raimondii* is more closely homologous with New World cottons than any other combinations.

The genom symbols assigned to different species, based on Beasley (1942), Stephens (1947b), Douwes (1951, 1953), Brown and Menzel (1952b) and Douwes and Cuany (1953) are presented in Table 62.

TABLE 62. GENOMS OF *Gossypium*

Species	Genom	Species	Genom
Old World (n=13)		New World (n=13)	
Afro-Asian:			
herbaceum	A_1	*thurberi*	D_1
arboreum	A_2	*armourianum*	D_2-1
anomalum	B_1	*harknessii*	D_2-2
triphyllum	B_2	*klotzschianum*	D_3-k
		klotzschianum var. *davidsonii*	D_3-d
stocksii	E_1	*aridum*	D_4
somalense	E_2	*raimondii*	D_5
areysianum	E_3	*gossypioides*	D_6
Australian:			
sturtii	C_1	*hirsutum*	$(AD)_1$
robinsonii	C_2	*barbadense*	$(AD)_2$
		tomentosum	$(AD)_3$

On the basis of genomic constitution, the wild diploid species can be grouped into four categories: (*i*) *anomalum* and *triphyllum* having a similar B genom; (*ii*) *stocksii*, *somalense* and *areysianum* with E genom; (*iii*) *sturtii* and *robinsonii* with C genom ; and (*iv*) New World wild species, *thurberi*, *armourianum*,

harknessii, *klotzschianum*, *klotzschianum* var. *davidsonii*, *aridum*, *raimondii*, and *gossypioides* having a common D genom; it may be mentioned further that *armourianum* and *harknessii* have similar genoms D_2. Closely related species usually have the same genom while distantly related species possess genoms showing low homologies between them.

The cultivated Old World species have A genom while the cultivated New World cottons have (AD) genom. To differentiate the A and D genoms of the cultivated American species from the A genom of the cultivated Old World and the D genom of the wild New World species, they are sometimes written as A_h or A_b and D_h or D_b for *hirsutum* or *barbadense* (Brown and Menzel, 1952a). The cultivated species of the Old World and the New World cross readily within their own group. The F_1 hybrids largely show regular bivalent pairing and are fully fertile. However, F_2 progenies show considerable depression in vigour and inbreeding results in the establishment of types practically indistinguishable from the parent species. Thus all intermediate types are at a great selective disadvantage and fail to establish themselves (Stephens, 1949). According to Harland (1936a, 1939) these species differences are mainly attributable to differences in 'genetic architecture', built up with a 'modifier complex' system independent of structural differentiation of the chromosomes: the respective genoms remain cytologically homologous throughout and yet differ in their genetic make-up. This is also called as the 'multiple gene substitution' theory. Later, on the basis of preferential pairing in synthetic allotetraploids, selective elimination of genes from the donor parent in certain interspecific backcrosses, and block transference of linked complexes, it was suggested by Stephens (1949) that the chromosomes of different species of *Gossypium* have manifold small scale structural differences that are not easily detected by cytological methods. Stebbins (1945, 1947) has termed this type of differentiation as 'cryptic structural differentiation.'

Apart from the differences due to 'multiple gene substitution' and 'cryptic structural differentiation', it is interesting to note that recently Gerstel (1953a) and Menzel and Brown (1954) have reported gross structural differences existing between the A genoms.

Gerstel (1953a) reported that *arboreum* and *herbaceum* differ by one reciprocal translocation in A genom chromosomes thus forming one IV in the F_1 hybrids; *herbaceum* and *hirsutum* by two translocations and form two IV in F_1 hybrids; and *arboreum* and *hirsutum* by three translocations, forming one IV—one VI in F_1 hybrids. Thus the multivalents formed in hybrids are due to segmental interchanges rather than due to polyploidy or duplication within the A genom. The end-arrangements of the five A chromosomes, as they are understood at present from all available evidence, are represented schematically (Fig. 32) by Menzel and Brown (1954). The identical behaviour of *barbadense* to that of *hirsutum* in its hybrids with **Herbacea** species has led

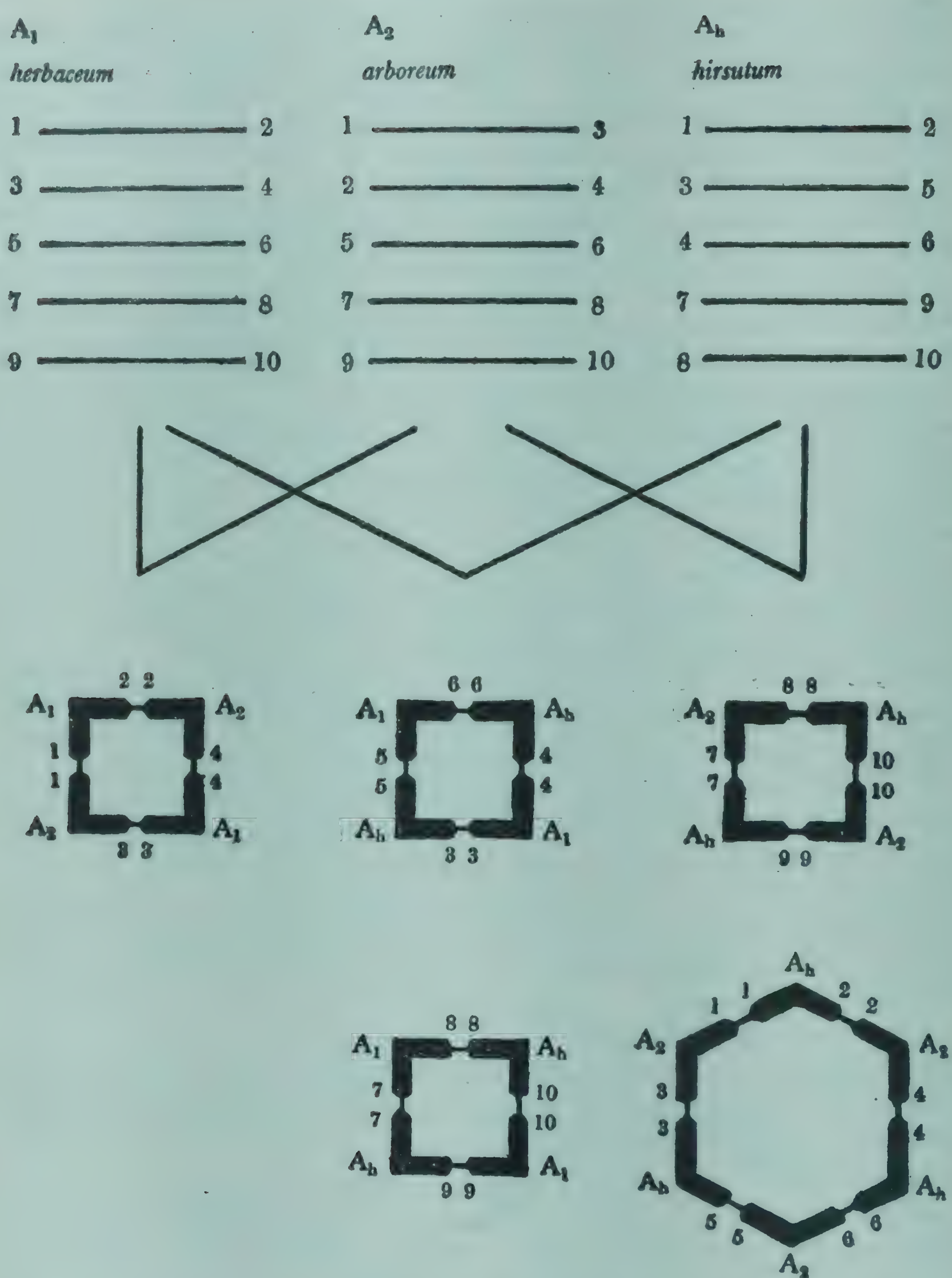


Fig. 32. Showing the end arrangements of the differential chromosomes in *herbaceum*, *arboreum* and A_h sub-genom of *hirsutum* and the type of M I pairing of these chromosomes in the three possible hybrid combi nations.

Gerstel and Sarvella (1956), to infer that the A genom of the two species is similar. Thus, in the genus *Gossypium*, only three major segmental interchanges have been found so far. Gerstel and Sarvella (1956) consider that it is most likely that these translocations involve entire arms or their major parts because they cause catenation in most of the pollen mother cells of the known structural hybrids.

According to Gerstel and Sarvella (1956), a consideration of the distribution of translocations in the genus indicates that they are limited to the A genom of the cultivated Old and New World species covering very extensive areas on the globe. No translocations have been found either in hybrids between D species nor in hybrids between the latter and the natural amphiploids (Brown and Menzel, 1952b, c). Douwes (1953) has studied pairing behaviour in hybrids between wild species of other sections. He saw only bivalent pairing in *anomalum* x *triphyllum* (B genom). Similarly he gave no evidence of translocations in the three species with E genom, *somalense*, *areysianum* and *stocksii*. All possible intra-sectional hybrids have now been studied cytologically. The only inter-sectional hybrids between diploid species with a chiasma frequency sufficient for multivalent formation are those involving the A and the B genoms. The B genom of *anomalum* has an arrangement similar to that of *herbaceum*.

Any explanation why the only translocations known in the genus are limited to one genom of the cultigens (disregarding *tomentosum*) must remain purely speculative.

It is tempting to exploit the A genom translocations for the establishment of phylogenetic relationships, even though reasoning based on a single characteristic is weak. Similarity of segmental arrangements has been used as an indication of relationship in other genera (Cleland, Preer and Gecklar, 1950), but with the argument that "similarities (in structure) are too frequent to be explicable in terms of chance." Any argument for phylogenetic significance of the A genom translocations in *Gossypium* could be based, in contrast, only on the rarity with which they occur in the genus and that a reversal of a particular translocation is, therefore, not a likely event. Thus a phylogenetic pathway from *anomalum* to *herbaceum* and thence to the New World species has been suggested (Gerstel, 1953a). In this scheme, *arboreum* would lie off the main route, because it is distinguished by an additional translocation from both *herbaceum* and the New World amphiploid species. It is widely agreed that *anomalum* is the most primitive species in this group. *Gossypium herbaceum* var. *africanum* could easily be the most primitive type of the species as plant morphology (Chevalier, 1936), chromosome morphology (Sikka, Rahman and Afzal, 1944) and evolutionary history of its pest, *Diparopsis castanea* (Hutchinson, 1954) would indicate. Besides the cytological evidence, the anatomical evidence (Abraham and Ayyar, 1938) also suggests that *herbaceum* is closer to the 4*x* **Hirsuta** species than *arboreum*. The possibility that

a species apparently centred in Africa may be closer to the New World cottons than the now largely Asian *arboreum* should be taken into account in the further discussion of the origin of the 4*x* cottons. It might be considered to weaken the hypothesis of a recent Pacific transfer of an Asian component of the 4*x* species, which was tentatively pronounced by Hutchinson, Silow and Stephens (1947). There is, of course, the alternative that the 4*x* cottons may be of early Tertiary Age as postulated by Stephens (1947b) and also by Harland who speculated a Polynesian origin of the 4*x* cotton and its subsequent travel to America *via* a land bridge connecting America with New Zealand and that the modern world distribution of the genus bears little relation to their phylogeny.

The problem of mono- *vs*. poly-phyletic origin of the three amphiploid species remains unsolved, except that all three have a segmental arrangement similar. Morphological characters, however, tell a different story. Wouters (1948) has commented on the striking similarility with respect to capsule characters between *arboreum* and *barbadense* on the one hand and *herbaceum* and *hirsutum* on the other. The future taxonomy of the genus will have to account for both sets of observations.

POLYPLOIDS AND THEIR HYBRIDS

Besides the naturally occurring allotetraploid species in *Gossypium*, several other auto-and allo-polyploids have been obtained and used in many different cross combinations. Cytogenetical investigations on this material have given valuable information regarding its utility in cotton breeding and also additional evidence for the genom inter-relationships in the genus.

Some of the polyploids in cotton have originated spontaneously, others have been produced artificially. A number of techniques have been used to produce polyploids by colchicine treatment. Beasley (1940b) obtained polyploids by the immersion of apical meristems in 0·2 per cent. aqueous solution of colchicine for 24 hours. This treatment caused 10 to 55 per cent. of the treated plants to produce polyploid branches. A system of formulae was also presented for making the composition of polyploids clear in which each chromosome set is given a capital letter and a number is placed before the letter to indicate the number of times a chromosome set is present. Stephens (1940) gave colchicine treatment to: (*i*) newly germinated seeds; (*ii*) plumules in the cotyledon stage; (*iii*) epical buds of the main stem; (*iv*) flower buds; and (*v*) young bolls. Two methods, proved successful: (*a*) on the second day after germination, the seeds were immersed for one to two days in 0·025 per cent. aqueous colchicine and were washed well with water before planting out; and (*b*) aqueous colchicine was applied to plumules just as their first leaves were on the point of unfolding. Ten to 25 drops of the solution were applied with a small brush, one by one, allowing time for each drop to dry before leaving the next. The most effective concentrations of the solution

were 0·5 and 1·0 per cent. Zhebrak and Rzaev (1940) in Russia produced amphidiploids by colchicine treatment of seeds and shoot apices. Another Russian worker, Zhurbin (1941) obtained polyploids by treating shoots and germinating seeds. In India, Amin (1941) found that germinated seeds dipped once or twice at an interval of six hours in solutions ranging from 0·25 to 0·01 per cent. of aqueous colchicine gave successful results, the success per cent. being as much as 22. Colchicine treatment given to the growing shoots of young seedlings by 'drop method' (concentration of aqueous solutions ranging from 1·0 to 2·0%) for a period of three to four weeks also proved to be equally successful. Recently Douwes (1952) has reported on two methods used by him for colchicine treatment of young cotton seedlings. (1) After soaking seeds in water for 24 hours, the seed coats were removed and the whole bare embryos directly exposed to the colchicine between pieces of blotting paper soaked in the solution. The two concentrations used were 0·025 and 0·050 per cent. in aqueous solution. At a temperature of 21° to 26° C., a 12 hour exposure to 0·025 per cent. (12 x 0·025 =dose 0·30), and an 8 hour exposure to 0·050 per cent. (dose =0·40) proved to be sub-lethal. Tetraploidy was induced within the range between these sub-lethal dosages on the one side and 4 hour in 0·025 per cent. (dose =0·10) or 1 hour in 0·050 per cent. (dose =0·50) on the other side. The optimal dosage was found to be near the sub-lethal side of this range. However, in this technique there is a severe toxic effect of colchicine, especially on the root system. (2) In the second method the seed coat was removed after about 24 hours soaking in water, but the treatment was postponed for four days after the commencement of the germination until the roots were long enough to allow treatment of the shoots only. The seedling was inverted with its growing point in a small tube of colchicine solution of 0·050 per cent. concentration. The heaviest treatment given was 10 hour (dose =0·50) at a temperature between 23° and 26° C. In this method tetraploidy was induced by a 2 hour treatment (dose=0·10) upwards, the optimal dosage likely to be near 0·30, a 6 hour treatment.

AUTOPLOIDS

Meiotic behaviour of chromosomes in the autotetraploids and haploids of the different *Gossypium* species is summarised in Table 63.

Autotetraploids of *thurberi* (4*n*) and of *hirsutum* and *barbadense* (8*x*) have been reported by Harland (1940). In India, autoploids of *davidsonii*, *raimondii* and *hirsutum* (Cambodia Co·2) have been reported from Surat (Bombay State), but there is no information regarding chromosome behaviour in them (Amin, 1940; Patel, Thakar and Deodikar, 1947). According to Beasley (1940b, 1942), about two-thirds of the chromosomes of autotetraploids form quadrivalents during meiosis. The 4*n* *arboreum* studied by Stephens (1942) showed cells with total number of associations less than 13 and individual associations with

TABLE 63. CHROMOSOME BEHAVIOUR IN AUTOPLOIDS OF *Gossypium*

Species	Chromosome number and genoms	Chromosome pairing at first metaphase							Author
		I	II	III	IV	VI	VIII	X	
	$4n=4(x_1, x_2)=104$								
hirsutum	4 $(AD)_1$	0·4	16·2	0·4	17·5				Beasley, 1942
barbadense	4 $(AD)_2$	0·8	14·2	0·8	18·1				,,
	$4n=4x=52$								
herbaceum	4 A_1	0·95	9·0	0·2	8·2				Iyengar, 1944a
arboreum (Red *arboreum*)	4 A_2	0·97	8·4	2·4	8·3				Patel, Thakar and Deodikar, 1947
arboreum race *indicum*									
(*i*) Gaorani 6	4 A_2	0·60	8·3	0·3	8·5				
(*ii*) Northern 14	4 A_2	0·7	4·3	0·3	6·6	0·9	1·0	0·2	Stephens, 1942, 1945
	$n=2x=26$								
hirsutum	$(AD)_1$	22·6	1·7						Beasley, 1942
hirsutum	$(AD)_1$	23·3	1·35						Brown and Menzel, 1952a
barbadense	$(AD)_2$	23·0	1·5						Webber, 1938

more than four chromosomes at first metaphase, which according to the author further supports the hypothesis that diploid *Gossypium* species are secondary polyploids.

On pollinating *hirsutum* cotton with *bhindi*, *Abelmoschus esculentus*, a plant with approximately double the number of chromosomes (*ca*. 104) was reported by Brown (1947). Phenotypically and cytologically there was no indication that *bhindi* chromosomes had taken part in the development of the variant plant. Absence of typical polyploid characteristics and low incidence of quadrivalency indicated that despite the approximate $4n$ number of chromosomes, they did not represent an exact duplication of the $2n$ complement but a modified assortment.

Beasley and Richmond (1941) reported the occurrence of a haploid in *hirsutum* population grown from seeds produced by pollinating normal flower with X-irradiated pollen. If the haploid were the result of X-irradiating pollen, the frequency of haploids obtained in this way is very low. Haploidy through twining in the 26-chromosome species *davidsonii** and *sturtii* has been reported by Skovsted (1935a) and Webber (1940). Similar polyembryonic haploidy has been described in the cultivated New World cottons by Harland (1936b). Twining is reported to be much more common in Sea Island (*barbadense*) cotton than in other cultivated cottons and most Sea Island twins are diploid/haploid whereas twins of the Old World cultivated species are usually diploid/diploid (Silow and Stephens, 1944). Beasley (1940b) utilised *hirsutum* and *barbadense* haploids towards production of pure lines in one step through chromosome duplication. Some more uses of haploids in elucidation of genetic problems or in practical cotton breeding have been suggested by Harland (1955b).

ALLOPLOIDS

In *Gossypium* alloploid plants containing genomal sets from two, three or four species have been obtained. These plants form a series with triploid, tetraploid, pentaploid, hexaploid and octoploid multiples of the basic chromosome number and have been obtained by chromosome duplication before or after hybridisation.

Triploids. Triploids comprising two similar and one dissimilar genom, are analogous to the interspecific hybrids between **Hirsuta** species on the one hand and the **Herbacea** or the New World diploid species on the other in their genomic constitution and chromosomal behaviour. Meiotic behaviour of the synthetic *Gossypium* triploids is summarised in Table 64.

The multivalents observed in some of the allotriploids may be due to segmental affinity between the genoms concerned or due to 13 not being the basic number in *Gossypium* but a balanced polyploid number. The small amount of trivalency in the triploid hybrids of 4*n*-*arboreum* with *sturtii* and *raimondii* confirms the existence of slight homologies between the chromosome

TABLE 64. MEIOTIC BEHAVIOUR IN ALLOTRIPLOIDS OF *Gossypium*

Cross combination	Genoms and constitution	Chromosome pairing at first metaphase							Author
		I	II	III	IV	V	VI	VII	
F_1 (*herbaceum* x *arboreum*) x *arboreum*	$3x_1$ $A_1, 2A_2$ $2x_1, x_2$	2·5	5·7	6·0	1·1	0·35	0·1	0·05	Skovsted, 1933
4n-arboreum x *anomalum*	$2A_2, B_1$	(data incomplete)		6·0	(1·6 multivalents)				Stephens, 1945
4n-arboreum x *sturtii*	$2A_2, C_1$	12·95	11·65	0·85	0·05				Stephens, 1942
4n-arboreum x *raimondii*	$2A_2, D_5$	13·36	12·28	0·36					,,
4n-arboreum x *armourianum*	$2A_2, D_{2\text{-}1}$	12·47	13·27						,,
4n-arboreum x *stocksii*	$2A_2, E_1$	13·0	13·0	(data incomplete)					Stephens, 1945

sets involved. Statistical comparison revealed that there is a tendency for C_1 (*sturtii*) to pair with A_2 (*arboreum*) more readily than do D (*raimondii*) and (*armourianum*) genom chromosomes, although in none of the three wild species is the degree of homology with *arboreum* of a high order (Stephens, 1942). Thus, general genotypic affinity estimated from chromosome pairing at meiosis in these triploids confirms that C is not closely homologous with A and that homologies between A and D are very low (Stephens, 1942).

Associations of more than three chromosomes at first metaphase of the triploid, F_1 (*herbaceum* x *arboreum*) x *arboreum*, were considered by Skovsted (1933, 1935a, 1937) to be indicative of homologies existing within $n=13$ chromosomes of *Gossypium*. His observations on this triploid led him to consider that the diploid *Gossypium* species were probably secondary polyploids of $(n = 6)$ x $(n = 7)$ parentage. Genetic evidence showed that the triploid hybrid was obtained as a result of functioning of an unreduced 26-chromosome male gamete from the F_1 (*herbaceum* x *arboreum*) where to bring in segmental interchange heterozygosity (of the type recorded recently by Gerstel, 1953b, in *herbaceum-arboreum* hybrids) into the resulting triploid hybrid, a part of the multivalency come across in the triploid would be expected on the basis of this structural hybridity. It is difficult to ascertain the relative extent of A_1-A_2 pairing and intra-genomal pairing in this triploid. In the triploid hybrids studied by Stephens (1942—Table 64), the interspecific homologies were considered to be, on the average, about twice as strong as the residual homologies existing within each wild diploid set of 13 chromosomes, since, in a total of 60 pollen mother cells, 26 trivalents but only 13 autosyndetic (intra-genomal) bivalents were formed.

Silow (1944a), as a result of extensive genetic analysis of the three Old World species *arboreum*, *herbaceum* and *anomalum*, concludes that inter-varietal and interspecific distinctions differ in degree only and not in kind. The same conception of a gradual quantitative differentiation during evolution still holds when comparison is transferred from the genetic to the cytological level. The degree of metaphase I pairing found in the triploid hybrids studied so far, forms a quantitative series, ranging from Skovsted's Old World triploid in which an average of only two to three chromosomes remain unpaired, to the 4*n* *arboreum* x *armourianum* triploid in which pairing between *arboreum* and *armourianum* chromosomes was not found (Stephens, 1945). Such a gradual discontinuity, according to Stephens (*loc. cit.*), could be brought about by differential accumulation of 'small' structural changes. The frequency of gross structural changes (e.g., inversions or changes in homology of sufficient magnitude to produce bridges) in interspecific hybrids which was found by Beasley (1942) suggests the likelihood that 'small' structural changes also occur. These cannot be detected cytologically though their presence may be inferred from restricted chromosome pairing in interspecific hybrids. In crosses between inter-fertile species they will behave as Mendelian units

and hence will be indistinguishable from true gene mutations. 'Small' structural changes would account for the continuity of the process of differentiation seen at all levels of speciation. The gradual quantitative change shown by Silow (1944) to be responsible for speciation in the *arboreum-herbaceum-anomalum* group is, thus a process which, according to Stephens (1945), has been continued throughout the genus, and gross structural changes have been superimposed on the basic mechanism.

In his studies on the allotriploids, Stephens (1942, 1945) obtained information on the cross compatibility relationships of the $2n$ and the $4n$ *arboreum* with various diploid cottons. The data showed that $2n$ *arboreum* either failed altogether to set viable seeds or set them rarely when pollinated by *armourianum*, *raimondii* or *sturtii*; the $4n$ *arboreum* on the contrary set viable seeds readily with pollen from these species (Stephens, 1942). To explain this phenomenon, Stephens suggested a hypothesis that a single D or C genom from the wild species was roughly equivalent to two A genoms in producing the 3 : 2 endosperm/zygote ratio necessary for viable seed production. The hypothesis was further tested in hybridisation of $4n$ *arboreum* with $2n$ species, *arboreum*, *herbaceum*, *anomalum* and *stocksii* (Stephens, 1945). On the 'balance' hypothesis of compatibility the genoms of these male parents should be roughly equivalent giving the normal 3 : 2 endosperm/zygote ratio, or its approximation, in inter-crosses since the F_1 hybrids of varying fertility are readily obtained. It would then be expected that $4n$ *arboreum* crossed by these species would give unbalanced endosperm/zygote ratios approximating 5 : 3 where the genoms were closely equivalent. The percentage of viable triploid seeds should, therefore, be inversely proportional to the degree of genom equivalence and in all such crosses should be low. The 'balance' hypothesis was supported by three out of the four combinations tested. The crosses $4n$ *arboreum* x $2n$ *arboreum* and $4n$ *arboreum* x *herbaceum* failed altogether. The cross $4n$ *arboreum* x *stocksii* gave a low proportion of viable seeds. *Gossypium anomalum*, which was almost fully compatible with $2n$ *arboreum*, was expected on the basis of the hypothesis to give still lower proportion of viable seeds in its cross with $4n$ *arboreum*. Actually, however, *anomalum* proved highly compatible with both $2n$ and $4n$ *arboreum*, a sitution that cannot be explained on a 'balance' hypothesis. It is thus clear that compatibility relationships are more complex (Stephens, 1945).

In their studies on the crossing behaviour of *G. gossypioides*, Brown and Menzel (1952b, c) found that the synthetic triploids, $2A_2$, D_6 : A_2 B_1 D_6 and A_2 E_1 D_6 obtained by crossing *gossypioides* with $4n$ *arboreum*, $4x$ (*arboreum-anomalum*) and $4x$ (*arboreum-stocksii*), respectively, died usually in the cotyledon stage. From a four species cross, $4x$ (*arboreum-stocksii*) x (*raimondii-gossypioides*), Menzel and Brown (1955) obtained a viable but sterile triploid, A_2 E_1 D. Similar triploid A_2 E_1 D_5, has been obtained from the cross $4x$ (*arboreum-stocksii*) x *raimondii* (Menzel and Brown, 1955).

TABLE 65. CHROMOSOME BEHAVIOUR IN THE DIFFERENT ALLOTETRAPLOID COMBINATIONS OF *Gossypium*

Combination	Genoms and constitution	Chromosome pairing at first metaphase					Remarks	Author
		I	II	III	IV	Others		
	$4x_1$							
1. Amph. (*herbaceum* x *arboreum*)	2 (A_1A_2)							
Amph. (1027 A L. F. x Gao-rani 6)		1·03	10·50	0·30	7·27		Boll setting fair (Amin, 1940)	Iyengar, 1947
Amph. (1027 A L. F. x Red *arboreum*)		0·98	12·59	0·53	6·08		,, ,,	,,
Amph. (1 A L. B. x Red *arboreum*)		1·45	11·58	0·28	6·66		,, ,,	,,
	$2x_1$; $2x_2$							
2. Amph. (*herbaceum*, 1027 A L. F. x *anomalum*)	2(A_1B_1)	0·7	22·47	0·43	1·27		Fertile (Amin, 1940)	,,
3. Amph. (*arboreum*, Karunganni 1 x *anomalum*)	2(A_2B_1)	0·40	22·69	0·42	1·25		,, ,,	Iyengar, 1942
		1·08	23·42	0·25	0·85		,, ,,	Iyengar, 1947
,, ,,		0·07	25·5	0·1			,, ,,	,,
4. Amph. (*davidsonii** x *anomalum*)	2($B_1D_{3\text{-}d}$)	1·22	25·0	0·09	0·13		Fertile	Brown, 1951
,, ,,		Usually 26II; higher associations frequent					Female fertile, Male sterile	Beasley, 1940c, 1942;
5. Amph. (*arboreum* x *thurberi*)	2(A_2D_1)							Harland, 1940
6. Amph. (*arboreum* x *thurberi*) x **Hirsuta** cultigen species	A_2D_1 (AD)	1 to 2	Mostly	One or more multi-valents in many cells				Beasley, 1940c
7. Amph. (*arboreum* x *thurberi*) x *hirsutum*	A_2D_1 $(AD)_1$	0·88	20·93	0·62	1·01	0·14V; 0·27VI; 0·02VII; 0·08 VIII; 0·02X		Brown and Menzel, 1950
8. Amph. (*arboreum* x *thurberi*) x *barbadense*	$A_2D_1(AD)_2$	2·7	18·3		1·0	1·0VI; 0·3VIII	3 cells only	Gerstel and Sarvella, 1956
9. F_2 (*barbadense* x *harknessii*)	$2A_b$, 2D		26 (usually)					Webber, 1939
10. Amph. (*hirsutum* x *herbaceum*, 1027 A L. F.) x *armourianum*	$(AD)_1A_1D_{2\text{-}1}$	1·44	23·67	0·77	0·33		Fertile	Iyengar, 1947
,, ,,		2·35	24·30	0·36			,,	,,
,, ,,		2·40	24·47	0·13	0·07		,,	,,

TABLE 65. CHROMOSOME BEHAVIOUR IN THE DIFFERENT ALLOTETRAPLOID COMBINATIONS OF *Gossypium* (*Contd.*)

Combination	Genoms and constitution	Chromosome pairing at first metaphase					Remarks	Author
		I	II	III	IV	Others		
11. Amph. (*hirsutum* x *herbaceum*) x *harknessii*	$(AD)_1A_1D_{2\text{-}2}$	1·84	22·14	1·14	0·54	0·05VI		Brown and Menzel, 1950
12. Amph. (*hirsutum* x *arboreum*) x *harknessii*	$(AD)_1A_2D_{2\text{-}2}$	1·37	22·36	0·31	1·09	0·01V; 0·08VI		,,
13. F_1 (*barbadense* x *thurberi*) x *arboreum*	$(AD)_2A_2D_1$		26 (usually)				An unreduced egg of the F_1 functioned.	Mauer, 1938
14. F_1 (**Hirsuta** cultigen x **Herbacea**) x *hirsutum*	$(AD)_1$, A, D	+	26 (usually) +		+		Fertile	Iyengar, 1944b
15. Amph. (*hirsutum* x **Herbacea**) x (*hirsutum*) [3-4]	$(AD)_1$; A, $D_{\bar{h}}$ $3x_1$; x_2	Segregation for presence and number of translocation multivalents entering into original cross					,,	Menzel and Brown, 1954
16. 4*n*-(*herbaceum*, 1 A L. B.) x *hirsutum*, Co. 2	$2A_1\ (AD)_1$	14·13	6·69	7·44	0·31	0·19V	Sterile	Iyengar, 1947
17. F_1 (*hirsutum-herbaceum*)	,,			Many			Self sterile, female fertile with *hirsutum*	Amin, 1940; Iyengar, 1947
18. Amph. (*herbaceum*, 1027A L. F. x *arboreum*, Red *arboreum*) x *hirsutum*, Co. 2	$2A\ (AD)_1$	10·92	15·50	2·25	0·83			Iyengar, 1947
19. F_1 (*arboreum* x *herbaceum*) x F_1 (*hirsutum* x *barbadense*)	2A (AD) $2x_1$; x_2; x_3	15·75	5·90	5·95	1·0	0·40V; 0·1VI	Sterile	Skovsted, 1934b
20. *hirsutum*, U.4 x Amph. (*herbaceum*, 1027 A L. F. x *anomalum*)	$(AD)_1\ A_1\ B_1$	9·17	18·67	1·67		0·08VI		Iyengar, 1947
21. *barbadense*, Sea Island x Amph. (*herbaceum*, 1027A L. F. x *anomalum*)	$(AD)_2\ A_1\ B_1$	14·1	16·08	0·67	0·33			,,
22. Amph. (*hirsutum* x *anomalum*) x *armourianum*	$(AD)_1\ B_1D_{2\text{-}1}$	8·90	17·50	2·00	0·20	0·10V; 0·10VIII		Iyengar, 1944b
,, ,,	,,	13·62	17·4	0·91	0·29	0·05V		,,
23 *barbadense* x 6*x*-(4*n*-*arboreum* x *sturtii*)	$(AD)_2\ A_2C_1$	13	14	2		1V (In a typical cell)	Sterile	Stephens, 1944b

Tetraploids. Tetraploids possessing varying doses of one, two or three different major genoms of *Gossypium* have been synthesized. Meiotic behaviour of chromosomes in them is summarised in Table 65. Amphiploids obtained from hybrids between two diploid species are listed first (Nos. 1 to 5). Of these, the tetraploids 2 (A_1 A_2); 2 (AB); 2 (BD) form a continuous series showing decreasing amount of meiotic irregularity. In these allotetraploids, it is noted from Tables 63 and 65 that there is a lower degree of quadrivalent formation than in the autoploids of **Herbacea** species. Partial homology shown by the B genom with A and D in hybrids at diploid level (Tables 55 and 57) is confirmed by the multivalency in the allotetraploids obtained from them. Beasley (1942) reported that the 4*x* (*arboreum-stocksii*), genomically 2(A_2 E_1), was almost normal in fertility indicating thereby that homology between the genoms A and E is very little. Another similar tetraploid reported in the literature is the 4*x* (*herbaceum* x *stocksii*) (Stephens and Cassidy, 1946). The tetraploid 2 (A_2 D_1) resembling the **Hirsuta** species or their hybrids in its genomic constitution, produced only female functional gametes though meiosis as studied from pollen mother cells was largely regular (Beasley, 1940c, 1942; Harland, 1940). Similar tetraploids containing A and D genoms like the **Hirsuta** species may be obtained in ways other than through amphiploidy in diploid interspecific hybrids. The different possible ways are :

1. Interspecific crosses in **Hirsuta.**
2. (2A, 2D) x 2 (AD) .. .. .. (Table 65: Nos. 6 to 8)
3. a. F_2 [(AD) x A]
   b. F_2 [(AD) x D] .. .. .. (Table 65: No. 9)
4. a. F_1 or Amph. [(AD) x A] x 2D .. (Table 65: Nos. 10 to 12)
   b. F_1 or Amph. [(AD) x D] x 2A .. (Table 65: No. 13)
5. a. F_1 or Amph. [(AD) x A] x 2 (AD) (Table 65: Nos. 14 and 15)
   b. F_1 or Amph. [(AD) x D] x 2 (AD)

In the methods 3,4 and 5 above, natural tetraploid species, 2 (AD) may be substituted by the artificially produced amphiploid (2A, 2D). Tetraploids obtained by the third method are rare since the triploid hybrids of 2 (AD) with 2A or 2D are usually self sterile. In methods 4 and 5, hybridisation with the amphiploids from the triploid F_1 hybrids is usually more successful than with the undoubled hybrids. In the fifth method, tetraploids are recovered when the amphiploids (6*x*) are crossed with a tetraploid for about three to four generations (Menzel and Brown, 1954) but when undoubled F_1 hybrids are crossed with the tetraploids, tetraploid plants may be obtained in the very first step (Iyengar, 1945). Cytology of the F_1 hybrids obtained by the first method has already been reviewed. Some of the other methods have successfully given tetraploid plants, chromosome behaviour in which is summarised in Table 66. The data accumulated over a period of years on the chromosome behaviour of some of these tetraploid derivatives

have been examined by Menzel and Brown (1954) in the light of the A genom translocations reported by Gerstel (1953a). These translocation figures enter into the cross combinations, Nos. 2, 4 and 5a, from which tetraploids of (2A, 2D) constitution have been obtained. Inferences drawn by Menzel and Brown (1954) regarding multivalency observed in these tetraploids are given below.

Multivalents in (2A, 2D) x 2(AD) Hybrids: In the hybrid, Amph. (*arboreum* x *thurberi*) x *hirsutum* (Table 65, No. 7), two out of 58 PMC's showed the expected pairing of 21 II, 1 IV, 1 VI. Two modes lay at 23 II, 1 VI and 24 II, 1 IV (5 and 6 cells, respectively). Configurations in 33 out of the 58 cells analysed could be accounted for on the basis of the A genom translocations. The remaining cells showed excess of multivalency. There is no evidence that any of the D genoms differs structurally from the D_h in such a way as to give multivalents. But there is considerable evidence that varying amounts of residual homology exist between various A and various D genoms. Metaphase pairing ranges from an average of 1·35 to 1·7 associations of two chromosomes per cell in *hirsutum* haploids (Beasley, 1942; Brown and Menzel, 1952a) to about 4·7 (Beasley, 1942) to 7·8 (Skovsted, 1937) in A_2 D_1 F_1 hybrids. Excess multivalency is, therefore, attributed to chiasmata between A and D chromosomes. This conclusion was supported by the fact that some of the multivalents were composed of large as well as small chromosomes although a majority were made up of large ones only.

In the A_2 D_1 $(AD)_1$ hybrids, not more than three chiasmata between A and D chromosomes need be postulated to account for pairing in any of the cells recorded; 18 of the 25 cells can be accounted for by assuming only one AD chiasma. It is of interest that this frequently seems to involve pairing between a D pair and the A_h A_2 hexavalent. In 10 of the 25 cells, either an VIII, a VII+I, or 1 III+1 V without I's was formed. The presence of X suggests that this D pair also has some homology with one of the A_h A_2 pairs, perhaps in the opposite arm. The frequent involvement of the VI in AD pairing suggests that the intergenomic pairing is not random, but rather confined to only a few segments of the D genoms.

The above interpretation given by Menzel and Brown (1954) is applicable to findings on another similar hybrid, Amph. (*arboreum* x *thurberi*) x *barbadense* (Table 65, No. 8).

The F_1 (A_2, D_1) x $(AD)_1$ was studied by Menzel and Brown (1954). The segregates comprised plants with both IV and/or VI; one of the plants possessed neither. It was inferred that the plant devoid of translocation figure may have become homozygous for either the A_h or the A_2 end arrangement whereas the others showed segregation for the presence of the two translocation figures. The F_2 plants had a lower frequency of cells with AD chiasmata than the F_1.

Multivalents in Amph. [(AD) x A] x 2D Hybrids: In the report on multi-

valency in such hybrids summarised in Table 65 (No. 11 and 12) data from several plants were combined. Menzel and Brown (1954) analysed sufficient cells in individual plants of similar hybrids obtained from four different cross combinations and compared the findings with those on the tetraploids obtained by the cross combination, Amph. (A x D) x 2 AD. Their analysed data are reproduced in Table 66. In the five individual tetraploids obtained by crossing the hexaploid with the diploid, the average number of chromosomes participating in multivalent formation was lower than in the hybrids obtained by tetraploid x tetraploid cross (Table 65, No. 1). In all the five individual plants, some cells showed multivalents in excess of those ascribed to A genom translocations, ranging from only one cell (2·5%) in $A_2D_{2\text{-}2}$ $(AD)_1$ hybrid (Table 66, No. 3) to 36 per cent. of the cells in the $A_1D_{2\text{-}2}$ $(AD)_1$ hybrid (Table 66, No. 6). In all five, the estimated frequency of AD pairing was lower than in the (A_2D_1) x $(AD)_1$ hybrids. The lower multivalent frequency in the five hexaploid x diploid hybrids suggests that none of them was heterozygous for all the chromosomes involved in the translocations. Backcross of the tetraploid hybrid from cross combination No. 4 (Table 66) to *hirsutum* gave 21 plants all of which exceeded the tetraploid hybrid parent in multivalent formation. All but one or two had the IV and all had the VI despite the fact that only 2 VI's were seen in the tetraploid hybrid parent. This indicated that the latter was probably a duplication deficiency type which had become homozygous for A_h end arrangements; multivalent formation should not have increased on backcrossing to *hirsutum*.

TABLE 66. COMPARISON OF METAPHASE PAIRING IN ALLOTETRAPLOIDS OF GENOM CONSTITUTION A, D, (AD)

Cross combination	Plants	Genom constitution	No. PMC	Average number chromosomes per cell paired as multivalents	Cells with excess multivalents		A D chiasmata per cell	
					Number	Per cent.	Mode	Max.
1. Amph. (*arboreum* x *thurberi*) x *hirsutum*	Many	$A_2D_1(AD)_1$	58	9·80	25	43·1	1	3
2. Amph. (*hirsutum* x *arboreum*) x *thurberi*	1	„	11	7·45	3	27·2	1	2
3. Amph. (*hirsutum* x *arboreum*) x *harknessii*	1	$A_2D_{2\text{-}2}(AD)_1$	42	5·74	1	2·5	1	1
4. „ „	1	„	25	4·64	4	16·0	1	1
5. Amph. (*hirsutum* x *arboreum*) x *raimondii*	1	$A_2D_5(AD)_1$	28	7·89	4	14·3	2	2
6. Amph. (*hirsutum* x *herbaceum*) x *harknessii*	1	$A_1D_{2\text{-}2}(AD)_1$	25	5·75	9	36·0	1	4

(See Menzel and Brown, 1954)

Multivalency reported in the hybrid Amph. (*hirsutum* x *herbaceum*) x *armourianum* (Table 65, No. 10) could be similarly interpreted. Mauer's report that the hybrid F_1 (*barbadense* x *thurberi*) x *arboreum* gave 26 bivalents at meiosis (Table 65, No. 13) is considered to be somewhat doubtful by Brown and Menzel (1950), as all A genom translocation heterozygosity should have been encountered.

Multivalents in Amph. $[(AD)_1 \times A] \times 2\ (AD)_1$ [3-4] *Hybrids :* On reexamining the data from backcrosses of the 6*x*—(*hirsutum* x **Herbacea**) to *hirsutum*, collected incidental to recovery and study of trisomic lines and without particular effort to isolate or maintain the translocations it was concluded that all of the multivalent formation in the pentaploid and later generations, above that attributable to aneuploidy can be accounted for by the A genom translocations. No pairing between A and D genoms need as postulated, lines carrying single translocation multivalents which subsequently behave cytologically as if they were reciprocal translocation within *hirsutum*, were readily isolated in plants having only 52 chromosomes. As cytogenetic tools these lines have the advantage over induced translocations in *hirsutum* that they are already known to involve the A_h rather than the D_h genom. Several such lines from crosses involving both *arboreum* and *herbaceum* have been established and are being tested against each other and against cytologically aberrant *hirsutum* lines to establish whether the same or different chromosomes are involved. Similar tetraploid plants were probably recovered by Iyengar (1944b) in the backcrosses, F_1 (**Hirsuta** cultigen x **Herbacea**) x *hirsutum*.

The 2A, 2D tetraploids obtained from the cross F_1 (*barbadense* x *aridum*) x *barbadense* (Method No. 5b) are reported to be self fertile (Skovsted, 1935a). These tetraploids would apparently be free from A genom translocations.

The (2A, 2D) tetraploid lines are also being obtained by using a 'doubled haploid', completely homozygous *hirsutum* type in the Method No. 5 (Meyer, 1954). Fourteen different alien characteristics from the 2*x* species are being transferred to the doubled haploid *hirsutum* by this method and the resulting isogenic 4*x* strains are expected to be useful for interspecific genom analysis and other studies.

The (3A, D) tetraploids have been studied by Skovsted (1934b), Amin (1940) and Iyengar (1947) (Table 65, Nos. 16 to 19). Skovsted (1934b) reported chromosome conjugation in his material similar to that in $3x_1$ triploid (Table 64), but with the addition of an extra set of 13 non-homologous chromosomes. The same inference is applicable to the behaviour of the other 3A, D tetraploids. In the hybrids studied by Iyengar (1947) univalents less than 13 were often met with ; this was asscribed to A-D pairing.

Tetraploids of the probable genomic constitutions 2A, B, D and A, B, 2D have been studied cytologically by Iyengar (1944b, 1947). Low degree of univalency in these hybrids was considered to be due to additional intergenomal

affinities between A-B, B-D and A-D sets. For the same reason, integrity of the D genom in these hybrids was in doubt; the hybrid parents $4x$ (*herbaceum-anomalum*) or $6x$ (*hirsutum-anomalum*) used in the cross combinations giving the tetraploid plants (Table 65, Nos. 20 to 22) are expected to pass down unassorted and/or substituted B genom to the offspring. A similar tetraploid, genomically probably $(AD)_1\ B_1D_{2\text{-}2}$, has been obtained by Brown and Menzel (1950) from the cross $6x$ (*hirsutum-anomalum*) x *harknessii;* its cytology has not yet been reported.

Deodikar (1949, 1950) obtained near tetraploids ($4x + 1$ to 3) in the cross, *hirsutum* x [Amph. (*hirsutum* x *anomalum*) x *hirsutum*]. Meiosis in these plants was characterised by the presence of univalents and/or trivalents, the maximum number of which in any individual plant was equal to the number of chromosomes in excess of $4x$-52 as seen in somatic counts. According to Deodikar, the extra one to three chromosomes represented the added number of *anomalum* B_1 genom, which remained either as univalents or occasionally formed trivalents with their partial homologous from *hirsutum* genoms, A and D. Meiosis in these plants was also characterised by loose distorted pairs during diplotene and chromatin bridges during anaphase and telophase. This was probably due to pairing of substituted *anomalum*, B_1, chromosomes with their partial homologues from the *hirsutum* complement, (AD_1). The number of substituted *anomalum* chromosomes was estimated to range from one to seven as the maximum number of anaphasic chromatin bridges in an individual were observed to vary from one to seven. Such 'alien substitution' and 'alien addition' plants enable, according to Deodikar, to avoid most of the economically undesirable wild characters except those located in the transferred chromosome itself. Besides isolation of such addition and substitution chromosome races, possibilities of an exchange of genes between A and D sets through the bridging influence of B set and transference of the genes from B to A and D chromosomes are considered to be very useful in plant breeding.

Cytology of the tetraploid 2A, C, D (Table 65, No. 23) was studied by Stephens (1944b). He reported an average of $11{\cdot}8 \pm 0{\cdot}8$ univalents per cell and concluded that the A genoms pair, but a very low degree of association exists between C and D genoms. This result suggested that *sturtii* is not an ancestor of the New World tetraploid cottons.

Tetraploids of the constitution A, E, 2D have been synthesized but their cytological behaviour has not yet been reported (Brown and Menzel, 1950). They are, $(AD)_1\ E_1\ D_{2\text{-}1}$, $(AD)_1\ E_1\ D_{2\text{-}2}$ and $(AD)_1\ E_1\ D_5$ obtained from the crosses of $6x$ (*hirsutum* x *stocksii*) with *armourianum*, *harknessii* and *raimondii*, respectively.

Pentaploids. Pentaploids with two or three different major genoms in them have been reported in *Gossypium*. Their meiotic behaviour is summarised in Table 67. Pentaploids of the constitution 2(AD), A were obtained

Table 67. Chromosome Behaviour in the Different Pentaploid Combinations of *Gossypium*

Combination	Genoms and constitution	Chromosome pairing at first metaphase					Author
		I	II	III	IV	Others	
1. F_1 (*barbadense* x *herbaceum*) x *barbadense*	$3x_1, 2x_2$ $2(AD)_2, A_1$	7·8	21·13	4·13	0·63	0·13V	Iyengar, 1943
2. F_1 (*herbaceum* x *barbadense*) x *hirsutum* ..	$2(AD), A_1$	11·39	18·74	3·53			,,
3. F_1 (*hirsutum* x *herbaceum*) x *hirsutum*	$2(AD)_1, A_1$	5·83	19·83	5·67	0·37	0·17V; 0·03VI	,,
4. F_1 (*hirsutum* x *arboreum*) x *hirsutum*	$2(AD)_1, A_2$	6·05	21·05	5·25	0·20	0·05VI	,,
5. 6 *x* -(*hirsutum* x *anomalum*) x *hirsutum*	$2x_1, 2x_2, x_3$ $2(AD)_1, B_1$	11·28	18·48	0·2	3·11	0·68VI	Deodikar, 1949

by Iyengar (1943) by backcrossing **Hirsuta** cultigen x **Herbacea** F_1 hybrids to a **Hirsuta** cultigen. The author reported that all the four pentaploids studied by him were characterised by the formation of many trivalents and in this respect conjugation was similar to that in triploids ($3x_1$) or tetraploid ($3x_1$, x^2) plants described by Skovsted (1933, 1934b) (Tables 64 and 65). Differences noticed in the mean values of conjugation amongst the pentaploids dealt with were attributed to factors other than homology affecting the chromosome conjugation (Iyengar, 1943).

Similar 2(AD), A pentaploids have been obtained by crossing 6*x* (**Hirsuta** cultigen x **Herbacea**) with a **Hirsuta** cultigen species. Menzel and Brown (1954) state that all the multivalent formation in these hybrids, above that attributable to ploidy, can be accounted for by the A genom translocations. This inference could very well be applicable to the observations reported earlier by Iyengar (1943) in similar material.

Multivalents observed by Deodikar (1949) in the hybrid 6*x* (*hirsutum* x *anomalum*) x *hirsutum*, were considered to have been formed through the bridging influence of B_1 chromosomes on the A_h and the D_h chromosomes. The multivalents showed chromatin bridges during their anaphasic separation. Majority of the *anomalum* chromosomes appeared as univalents. As expected, trivalency in this pentaploid is lesser than that reported by Iyenger (1943) for the 2(AD), A plants.

Brown and Menzel (1952a) have reported pentaploids of the following genomic constitutions.

Cross combination	Genomal constitution	Average number trivalents per cell
6*x*-(*hirsutum-herbaceum*) x *hirsutum*	$2(AD)_1$, A_1	
6*x*-(*hirsutum-arboreum*) x *hirsutum*	$2(AD)_1$, A_2	
6*x*-(*hirsutum-anomalum*) x *hirsutum*	$2(AD)_1$, B_1	1·79
6*x*-(*hirsutum-sturtii*) x *hirsutum*	$2(AD)_1$, C_1	
6*x*-(*hirsutum-stocksii*) x *hirsutum*	$2(AD)_1$, E_1	
6*x*-(*hirsutum-thurberi*) x *hirsutum*	$2(AD)_1$, D_1	
6*x*-(*hirsutum-armourianum*) x *hirsutum*	$2(AD)_1$, $D_{2\text{-}1}$	5·43
6*x*-(*hirsutum-harknessii*) x *hirsutum*	$2(AD)_1$, $D_{2\text{-}2}$	3·80
6*x*-(*hirsutum-raimondii*) x *hirsutum*	$2(AD)_1$, D_5	3·22

The authors point out that preferential pairing is expected in these hybrids, between the two (AD) sets, but since the extra genom lacks its other homologue, certain amount of its pairing with chromosomes from A_h and D_h genoms is expected. When the extra genom, therefore, is similar to one of the constituents genoms trivalency is greater than when it is alien: this is evident from the findings reported by Brown and Menzel in the above table and by Iyengar and Deodikar (Table 67).

All the pentaploids studied so far have been reported to be more or less fertile on backcrossing to **Hirsuta** species.

Hexaploids. Hexaploids with two to four different major genoms have been reported in *Gossypium*. Their meiotic behaviour is summarised in Tables 68 and 69. Brown and Menzel (1952a) compared the degree of bivalency shown by the triploid hybrids, **Hirsuta** x a diploid species, with the degree of quadrivalency shown by the derived hexaploids. Quadrivalency in the hexaploids was much less than that expected on the basis of bivalency in the parental triploids hybrids. This they attributed to selective pairing in the different genomal sets of the hexaploids. Selective pairing in the B_1 genom of the 6*x* (**Hirsuta** x *anomalum*) is most conspicuous. It may also be noted from Table 68 that quadrivalency is greater in hexaploids where **Hirsuta** genoms and an extra genom similar to one of the ancestral genoms of **Hirsuta** species are brought together, than in hexaploids containing one **Hirsuta** genom and an alien genom. In both the types of hexaploids quadrivalency is far less than that expected on the basis of genom relationships. In the former case, Brown and Menzel (1952a) consider that it is probably a function of both low chiasma frequency in the genus (Stephens, 1950b) and selective pairing in the genoms.

As mentioned earlier, Brown and Menzel (1952a) obtained pentaploids on crossing the hexaploids with *hirsutum*. Corresponding to the quadrivalency in the parental hexaploids, trivalency was expected in these pentaploids through pairing of the bivalents of **Hirsuta** genoms, (AD), with the single

TABLE 68. CHROMOSOME BEHAVIOUR IN THE DIFFERENT HEXAPLOID COMBINATIONS OF *Gossypium*

Combination	Genoms and constitution	Chromosome pairing at first metaphase					Maximum	Author
		I	II	III	IV	Others		
	$4x_1$; $2x_2$							
1. Amph. (*hirsutum* x *herbaceum*)	2 $(AD)_1$, $2A_1$	1·29	29·50	0·88	3·58	0·13VI	7	Iyengar, 1944b
2. Amph. (*hirsutum* x *herbaceum*)	2 $(AD)_1$, $2A_1$	0·97	25·62	1·16	5·19	0·06V; 0·19VI	10	Brown and Menzel, 1952a
3. Amph. (*barbadense* x *herbaceum*)	2 $(AD)_2$, $2A_1$	2·13	34·63	1·38	0·63		3	Iyengar, 1944b (average from data for two plants)
4. Amph. (*hirsutum* x *arboreum*)	2 $(AD)_1$, $2A_2$	1·5	28·50	1·13	2·38	0·13V; 1·0VI	5	Iyengar, 1944b
5. Amph. (*hirsutum* x *arboreum*)	2 $(AD)_1$, $2A_2$	1·27	27·5	0·80	4·42	0·04V; 0·15VI; 0·04 VIII	10	Brown and Menzel, 1952a
6. Amph. (*hirsutum* x *thurberi*)	2 $(AD)_1$, $2D_1$	0·9	28·72	0·59	4·40	0·04V	10	,,
7. Amph. (*barbadense* x *thurberi*)	2 $(AD)_2$, $2D_1$	0·67	33·96	0·42	2·00	0·04VI	6	Iyengar, 1944b
8. Amph. (*hirsutum* x *armourianum*)	2 $(AD)_1$, $2D_{2\text{-}1}$	1·26	25·81	1·18	5·19		12	Brown, 1951
9. Amph. (*barbadense* x *armourianum*)	2 $(AD)_2$, $2D_{2\text{-}1}$	2·32	32·75	0·86	1·75	0·02V; 0·04VI	5	Iyengar, 1944b
10. Amph. (*hirsutum* x *harknessii*)	2 $(AD)_1$, $2D_{2\text{-}2}$	2·16	29·09	1·03	3·54	0·03VI	7	Brown and Menzel, 1952a
11. Amph. (*hirsutum* x *raimondii*)	2 $(AD)_1$, $2D_5$	0·93	27·93	0·31	4·34		9	,,
	$2x_1$, $2x_2$, $2x_3$							
12. Amph. (*hirsutum* x *anomalum*)	2 $(AD)_1$, $2B_1$	2·9	35·43	0·5	0·6	0·07V	2	Iyengar, 1944b
13. Amph. (*hirsutum* x *anomalum*)	2 $(AD)_1$, $2B_1$	1·34	35·71	0·58	0·71	0·11VI	3	Brown and Menzel, 1952a
14. Amph. (*barbadense* x *anomalum*)	2 $(AD)_2$, $2B_1$	1·7	36·5	0·3	0·5	0·05VIII	2	Iyengar, 1944b
15. Amph. (*hirsutum* x *sturtii*)	2 $(AD)_1$, $2C_1$	1·68	36·54	0·32	0·57		2	Brown and Menzel, 1952a
16. Amph. (*hirsutum* x *stocksii*)	2 $(AD)_1$, $2E_1$	1·16	38·06	0·13	0·06		1	,,

chromosomes of the extra non-**Hirsuta** genom. To facilitate discussion, Brown and Menzel designated the non-**Hirsuta** genoms as 'N' or 'M'. They pointed out that the maximum pairing between (AD) and N genoms in triploid hybrids is greatly reduced in hexaploids obtained from them, probably because of preferential pairing and low chiasma frequency. Theoretically they expected selective pairing of the two (AD) genoms to persist in the pentaploids but since the N genom lacked homologues, increased (AD)-N pairing was also expected. On these considerations, they expected the hybrid combination series comprising $3x$=(AD), N; $5x$=2 (AD), N and $6x$=2(AD), 2N to show progressive reduction in (AD), N pairing, resulting in number of bivalents in triploids being more than the number of trivalents in the corresponding pentaploids and the latter in turn being greater than the number of quadrivalents in the corresponding hexaploids. In order to test this assumption, Brown and Menzel assembled data as follows.

Genom N	Genoms of hybrid combination and ploidy	(AD), N $3x$	2(AD), N $5x$	2(AD), 2N $6x$
	Chromosomal associations at M I	II/cell	III/cell	IV/cell
A_1		(13) Mostly	4·13-5·67	0·63-5·19
A_2		(13) ,,	3·53	2·13-4·42
$D_{2\text{-}1}$		(13) ,,	5·43	4·43-4·90
$D_{2\text{-}2}$		(13) ,,	3·80	3·54
D_5		(13) ,,	3·22	4·34
B_1		2·6—10·48 or even (13) maximum	1·79	0·50-0·71

From these data it appeared that the difference between III association in the pentaploids and IV frequency in the hexaploids was of doubtful significance. Absence of a homologous set of chromosomes apparently did not increase the ability of N to pair with (AD). Competition seemed to operate in the formation of the characteristically low number of chiasmata seen at metaphase, so that partially non-homologous chromosomes were unable to compete effectively for chiasmata with a genom in **Hirsuta** when a second **Hirsuta** component was present. The authors emphasise that these considerations are germane to the analysis of the hexaploid hybrid combinations of the type, [2(AD), 2N]x [2(AD), 2M]=(AD)N/(AD)M=2(AD), N M. In such hybrids it could be assumed that pairing between (AD) on one hand and N or M on the other is no greater than it is in the respective hexaploid parents. Meiotic behaviour of such hexaploid hybrids, as summarised by Brown and Menzel (1952a) is reproduced in Table 69.

The principal interest in meiotic pairing in the hexaploid combinations lies in the opportunity they afford for estimating the homology between the

TABLE 69. MEIOTIC BEHAVIOUR IN HEXAPLOID x HEXAPLOID HYBRIDS AND COMPARISON OF THE EXTENT OF PAIRING BETWEEN NON-**Hirsuta** DIPLOID GENOMS IN THEM AND IN CORRESPONDING DIPLOID F_1 HYBRIDS.

Combination $(AD)_1M$/ $(AD)_1N$	Genoms 2 (AD) + Non-**Hirsuta** genoms M and N		Chromosome pairing at first metaphase								Estimated M-N pairing in the hexaploid hybrid		Actual M-N pairing in direct F_1 diploid hybrids (average II) and Authors
	M	N	I	II	III	IV	V	VI	VII	Others	Av.	Max.	
1. Amph. (*hirsutum* x *herbaceum*) x Amph. (*hirsutum* x *arboreum*)	A_1	A_2	2·16	24·56	1·46	5·13	0·13	0·05	0·03	0·03VIII	10·81	13	(13) Mostly
2. Amph. (*hirsutum* x *herbaceum*) x Amph. (*hirsutum* x *anomalum*)	A_1	B_1	5·89	22·68	4·20	2·34	0·55	0·09	0·07	0·05VIII; 0·05IX; 0·02X	7·43	10	11·8-12·25 (Table 55)
3. Amph. (*hirsutum* x *arboreum*) x Amph. (*hirsutum* x *anomalum*)	A_2	B_1	9·41	20·07	6·34	1·72	0·34	0·07	0·03		4·79	9	9·1—11·8 (,,)
4. Amph. (*hirsutum* x *arboreum*) x Amph. (*hirsutum* x *anomalum*)	,,	,,	6·80	22·61	3·96	2·19	0·54	0·23	0·08	0·04XII	7·07	10	
5. Amph. (*hirsutum* x *arboreum*) x Amph. (*hirsutum* x *sturtii*)	A_2	C_1	11·11	23·19	5·27	1·00		0·07			4·30	8	0-8 (Webber, 1936); 9·5-10·2 (Skovsted, 1937)
6. Amph. (*hirsutum* x *thurberi*) x Amph. (*hirsutum* x *arboreum*)	D_1	A_2	10·50	15·94	8·90	1·28	0·44	0·09	0·06	0·03VIII; 0·03IX	2·81	7	6·35-9·56 (Skovsted, 1937) 0·2-1·02 (Webber, 1938, 1939); 2-6 (Iyengar, 1943)
7. Amph. (*hirsutum* x *herbaceum*) x Amph. (*hirsutum* x *raimondii*)	A_1	D_5	11·16	17·33	10·16	0·12	0·16				2·12	5	
8. Amph. (*hirsutum* x *arboreum*) x Amph. (*hirsutum* x *raimondii*)	A_1	D_5	8·04	14·73	11·57	0·61	0·19	0·35			2·61	5	

9.	Amph. (*hirsutum* x *herbaceum*) x Amph. (*hirsutum* x *stocksii*)	A_1	E_1	13·38	20·00	5·50	1·27	0·19	0·11	0·04	2·77	6	
10.	Amph. (*hirsutum* x *arboreum*) x Amph. (*hirsutum* x *stocksii*)	A_2	E_1	15·85	20·08	5·97	0·67	0·20	0·03	0·03	2·00	6	0·95-7·13 (Table 55)
11.	Amph. (*hirsutum* x *anomalum*) x Amph. (*hirsutum* x *sturtii*)	B_1	C_1	19·27	25·92	1·50	0·19				2·19	9	
12.	Amph. (*hirsutum* x *thurberi*) x Amph. (*hirsutum* x *anomalum*)	D_1	B_1	14·28	20·34	7·05	0·30	0·05			2·07	4	5·7 (Skovsted, 1937)
13.	Amph. (*hirsutum* x *anomalum*) x Amph. (*hirsutum* x *raimondii*)	B_1	D_5	12·22	19·27	7·70	0·75	0·05	0·07		2·70	5	
14.	Amph. (*hirsutum* x *anomalum*) x Amph. (*hirsutum* x *stocksii*)	B_1	E_1	20·55	25·55	1·90	0·05				1·55	6	2·7 (Douwes, 1951)
15.	Amph. (*hirsutum* x *thurberi*) x Amph. (*hirsutum* x *sturtii*))	D_1	C_1	14·43	22·22	5·24	0·55	0·04			1·73	5	0·74 (Webber, 1939)
16.	Amph. (*hirsutum* x *sturtii*) x Amph. (*hirsutum* x *raimondii*)	C_1	D_5	13·46	19·23	8·38	0·15	0·04			2·00	5	
17.	Amph. (*hirsutum* x *sturtii*) x Amph. (*hirsutum* x *stocksii*)	C_1	E_1	21·16	26·76	0·72	0·20				1·88	5	
18.	Amph. (*hirsutum* x *raimondii*) x Amph. (*hirsutum* x *stocksii*)	D_5	E_1	15·89	21·32	6·21	0·10				1·68	4	

diploid genoms, M and N. If M and N are entirely non-homologous, they will each form a number of trivalents with **Hirsuta** pairs of similar magnitude to the number of quadrivalents formed in the corresponding hexaploids. The remaining chromosomes of M and N:

26-[(AD)-M and (AD)-N trivalents in the hexaploid (AD)M (AD)N] or 26-[(AD)-M quadrivalents in the hexaploid 2(AD), 2M and (AD)-N quadrivalents in the hexaploid 2(AD), 2N]

will remain as univalents. The disparity between frequency of univalency expected in this way and that actually obtained provides a rough estimate of M-N pairing. By this method pairs of genoms may be arranged in order of their affinity.

Brown and Menzel (1952a) describe the following method for a more precise estimation of pairing between M and N genoms.

If only (AD) pairs, and (AD)-N and (AD)-M trivalent are formed, the maximum number of associations possible is 26. The excess above 26 is taken as the number of M-N associations. The error due to the occurrence of associations of more than three chromosomes is corrected thus : II's and III's are counted as one association; VI's, V's and IV's are counted as two associations (equivalent to 2II's, 1 II + 1 III, 2 III's, respectively); VII's, VIII's IX's are counted as three associations, etc.

More than 26 associations could be formed even in the absence of N-M pairing, e.g., when a IV or two II's of composition N A_h A_h M (or N D_h + D_h M) are formed, or when two homologous (AD) chromosomes each pair as II's with two different N or M chromosomes, D_h N_1 + D_h N_2. This error could be corrected by considering the frequency of 14 + associations per cell and of III formation in the triploid hybrids, (AD) N, but since these are rare and in the triploids, it is assumed that the error is negligible.

The estimates of average and maximum N-M pairing obtained by the above method are entered in Table 69, together with similar pairing actually reported in the corresponding F_1 diploid hybrids, if obtained. Brown and Menzel (1952a) observed from these data that, in general, only the estimated maximum M-N pairing in hexaploids approached the highest average bivalency value reported for the corresponding diploid hybrids. The case of C_1 D_1 and B_1 E_1 pairing were exceptional because the reported values for their pairing were much lower than the estimated values. In the diploid hybrid B_1 E_1, however, maximum of 6 II were formed in one cell; this figure of bivalents corresponds to the maximum estimated figure at the hexaploid level. Similarly, in hybrids analogous to the C_1 D_1 hybrid, Skovsted (1937) reported greater bivalency (7·65 II in C_1 D_{2-1} and 4·75 II in C_1 D_3). Brown and Menzel (1952a), therefore, considered it likely that C_1 D_1 also usually exhibits more pairing than what Webber (1939) reported. As regards diploid interspecific hybrids not hitherto obtained, Brown and Menzel (1952a) conclude that it should be possible to predict approximately

the extent of pairing in them and thereby assess the genom affinites on the basis of observations on meiotic behaviour of the corresponding hexaploids. Thus, there is nearly as much homology between B_1 and C_1 as between A and B or A and C; and E_1 is about equally distinct from A, B, C and D. By the methods described, it has been possible to study directly the cytological affinity of each genom group (major genom) in *Gossypium* with every other genom group. The relationships thus established are, in general, in excellent agreement with the inferences of the previous investigators from less direct evidence (Hutchinson, Silow and Stephens, 1947).

All the hexaploids obtained directly from the triploid hybrids, almost completely sterile, are more or less fertile. The hexaploid hybrid combinations on the other hand are generally not self fertile, particularly when the constituent genoms are very widely inter-related. These hexaploid hybrids are very infertile with *hirsutum* also but with persistent attempts a few seeds can be obtained from several of them.

Octoploids. Beasley (1942) has reported chromosome behaviour in Amph. (*hirsutum* x *barbadense*) : $8x=104$, genomically $2(AD)_1$, $2(AD)_2$. Average of 0·7 I, 0·7 II and 15·2 IV were observed at first metaphase. It was inferred that there was very little preferential pairing and hence very little structural differentiation between the chromosomes of the two **Hirsuta** genom groups.

Aneuploids. Interspecific or inter-generic hybridization, and also irradiation experiments have given aneuploid plants. Webber (1939) recovered 48 to 52 chromosome plants in the F_2 (*barbadense* x *harknessii*). First backcross plants of the origin, (**Hirsuta** cultigen x **Herbacea**) x **Hirsuta** cultigen, showed chromosome numbers ranging from 50 to 80 (Iyengar, 1945). The deficient aneuploid with 50 chromosome gave fertile 52-chromosome plants in later generations indicating that it was monosomic for two of its chromosomes. The euploid with 65 chromosomes (Pentaploid), in turn gave further aneuploid offspring in which the chromosome numbers ranged from 53 to 67. These aneuploids showed a wide variation in general morphology, maturity and fertility, and meiosis was complicated by the formation of multivalents (Iyengar, 1945). Trisomic derivatives from the various allo-hexaploids, $6x$-($4x$ x $2x$), have been reported by Brown (1949). The extra chromosome in trisomics affected some characters of leaf, bracteole, flower, boll, seed and fibres. Cytological study of chromosome pairing in trisomic plants has yielded additional information on the differentiation of specific chromosomes besides confirming the earlier conclusion on species of relationships based on studies of F_1 hybrids and their polyploids. The trisomics in turn gave rise to partially stable tetrasomic lines with an extra pair of chromosomes from the diploid species. Monosomic plants, some phenotypically normal, were found occurring spontaneously, as a result of non-disjunction in trisomic lines. Substitution forms

with one chromosome from a wild species in place of one of the cultivated genom were recovered, which could be recognised by the presence of characters carried by the introduced chromosome or by aberrant cytological behaviour. In the first backcross, Amph. (*hirsutum* x *anomalum*) x *hirsutum*, plants with 61 to 65 chromosomes were reported by Deodikar (1949). In the second backcross to *hirsutum*, chromosome numbers ranged from 56 to 75 when the first backcross hybrid was used as a female parent. On the other hand, when the latter was used as the male parent and *hirsutum* as the female parent, plants with 53 to 55 chromosomes only were recovered (Deodikar, 1950). Meiosis in these plants was characterised by the presence of, apart from bivalents, univalents and/or trivalents, the maximum number of which in any individual plant was equal to the number of chromosomes in excess of 52. The extra one to three chromosomes represented the added number of *anomalum* (B_1 genom) chromosomes, which remained either as univalents or occasionally formed trivalents with their partial homologous from *hirsutum* complement.

Brown (1947) has reported on a case of spontaneous reduction of chromosome number in somatic tissue of cotton. As a result of pollinating *hirsutum* cotton with *bhindi*, *Abelmoschus esculentus*, a plant containing approximately twice the number of chromosomes of cotton was obtained. Phenotypically and cytologically there were no indications that *bhindi* chromosomes had taken part in the development of the variant plant. The absence of typical polyploid characteristics and the low incidence of quadrivalents indicated that despite the approximate $4x(=8x)$ number of chromosomes, the chromosomes did not represent an exact duplication of the $2n$ complex, but a modified assortment. After several seasons, the number of chromosomes was reduced to monosomic level, $2n$-1, in a grafted branch. This somatic reduction in chromosome number to a number approximating the normal complex, whether by chance or in response to an unfavourable genotypic environment, represents a mechanism whereby unbalanced plant types may eliminate incompatible chromosomes and thus establish more viable forms.

Monosomics were also obtained from the seeds of *hirsutum* which had been exposed to gamma radiation of unknown intensity and duration at the time of the explosion of the first atom bomb at Bikini (Brown, 1950). Simple monosomics could also be recovered from translocation heterozygotes produced in the same irradiated material (Menzel and Brown, 1952a). Experiments with asynaptic plants for the production of monosomics have given disappointing results but the radiation method could probably be a more promising method for obtaining them (Menzel and Brown, 1952a).

STRUCTURAL VARIATIONS IN CHROMOSOMES

Brown (1950) produced evidence to show that gamma radiation as released during the explosion of an atomic bomb was highly effective in generating

hereditary changes in chromosome structure. Cytological analysis of the meiotic division stages of pollen mother cells collected from cotton plants (*hirsutum* : Acala 911) grown from exposed seed revealed irregularities in chromosome pairing which could be attributed to fragmentation and translocation of chromosome parts, and possible intra-chromosomal changes. These structural changes detected in the meiotic divisions of flower buds were probably those which survived many generation of somatic division during the growth of the plant from its dormant embryonic state at the time of exposure to gamma radiations. By analogy with the results obtained from other types of irradiation, it seemed reasonable to assume that minute rearrangements and deletions may also have been produced in this material.

One of the translocations reported is of special interest not only because of its cytological behaviour but also because of the importance of some of its derivatives in cytogenetic investigations. It originally appeared in a plant designated, 2 B-1 (Brown, 1950) and has been maintained by selfing and crossing (Menzel and Brown, 1952a; Menzel, 1955). So far as could be seen at first metaphase in the pollen mother cells (the earliest stage of meiosis which can be studied readily in cotton), it behaved as if it were non-reciprocal (Menzel and Brown, 1952d). The characteristic configurations in the translocation heterozygotes, in addition to 24 bivalents, were : the heteromorphic bivalent associated with two univalents—one larger than the other, the two heteromor-

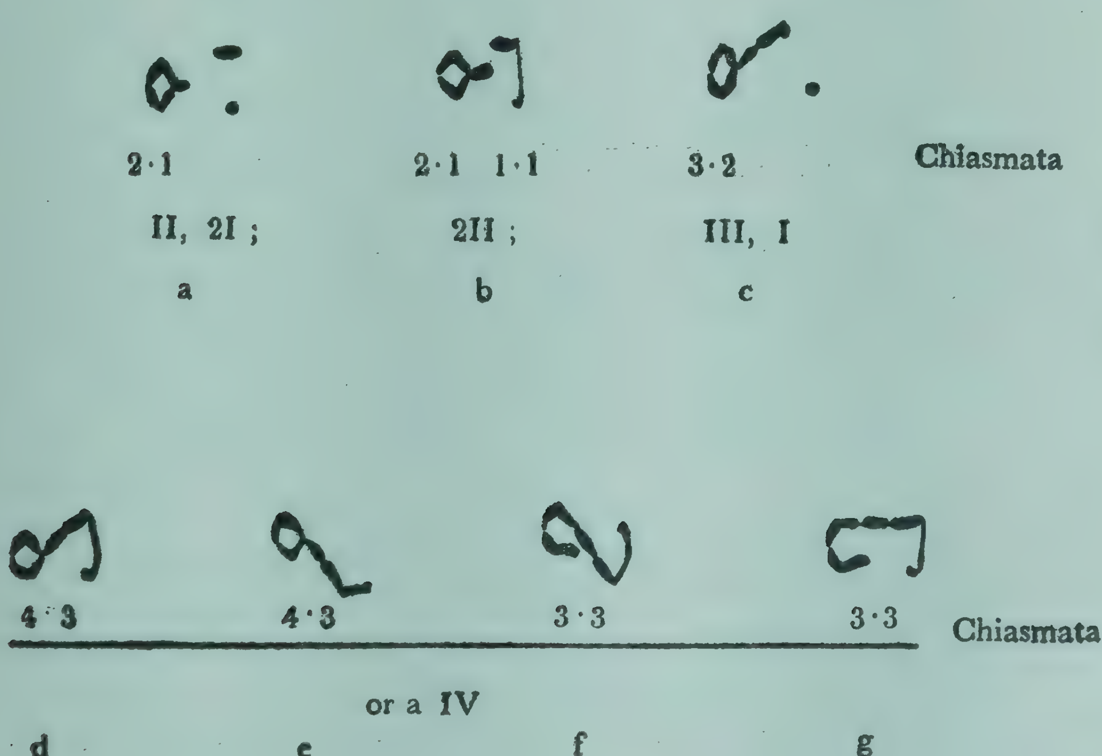


Fig. 33. First metaphase configurations, excluding normal 24 II, in the translocation heterozygotes like the 2 B-1 plant of *hirsutum* (from Menzel and Brown, 1952a).

phic bivalents, the trivalents showing four parts associated with a small univalent and the quadrivalent made up of five parts (Fig. 33).

Nearly 67 per cent. of the cells showed a quadrivalent each but none of them was of a closed ring type. One of the bivalents (Fig. 33a,b) and one of the constituent pairs in the multivalent associations (Fig. 33c,d,e), always showed one terminal and one sub-terminal chiasma.

In order to facilitate the description of structural changes inferred from these observations, Menzel and Brown (1952a) and Menzel (1955) have assigned numerals and letters to chromosomes or chromosome ends and segments which are not intended as a permanent scheme in the genus (Fig. 34 and Table 70). They inferred that in a chromosome with sub-terminal centromere (chromosome 2), a break occurred in the longer arm close to the centromere and proximal to the segment in which chiasmata are formed. The centric fragment of chromosome 2 was designated as 'C' and most of the long arm of chromosome 2 fragmented from it was designated as 'A'. 'A' appeared to have been translocated terminally to one arm of another chromosome with approximately median centromere (chromosome 1). Since there is no evidence that broken ends of chromosomes ever unite with unbroken ends, the authors assumed that a minute terminal segment of chromosome 1 (designated 'x') was broken off. The point of attachment of 'A' on chromosome 1 was, therefore, very likely sub-terminal and distal to the chiasma forming region. Menzel and Brown (1952a) did not obtain any cytological evidence regarding the fate of 'x' segment but they came across an indirect evidence which suggested that the 'x' segment contained functional chromating and changed places with the 'A' segment. Among the various derivatives of the translocation heterozygote, were a few dwarf plants which had the chromosomal constitution, either 24II + 2 (Chr. 1 altered)+ 2 (Chr. 2 normal) or 24II + 2(Chr. 1 altered) + 1(Chr. 2 normal). These classes of dwarf plants were, respectively, tetrasomic or trisomic for the segment 'A'; dwarfness, therefore, could not be attributed to tetrasomy. Both the dwarf types were assumed to be homozygous deficiencies of the segment 'X'. As expected on the basis of this assumption, the translocation homozygotes and the plant of the chromosome constitution, 24II + 2(Chr. 1 altered) + 2(Chr. 2 normal) + 1 (Chr. 2 altered) turned out to the normal and not dwarfs. The translocation was, therefore, actually reciprocal though very unequal. As a consequence, at first metaphase in the translocation heterozygotes, an interstitial chiasma was present proximal to the point of attachment of the arm 'A' in about 98 per cent. of the pollen mother cells, whereas the 'X' end was never paired. These relationships made it possible to determine the presence or absence of chiasmata at first metaphase with a high degree of accuracy at six different positions (a to f) in the quadrivalent. Also, because of these morphological features of the translocation, it was possible to demonstrate from the study of mataphase I that a wide array of viable, fertile

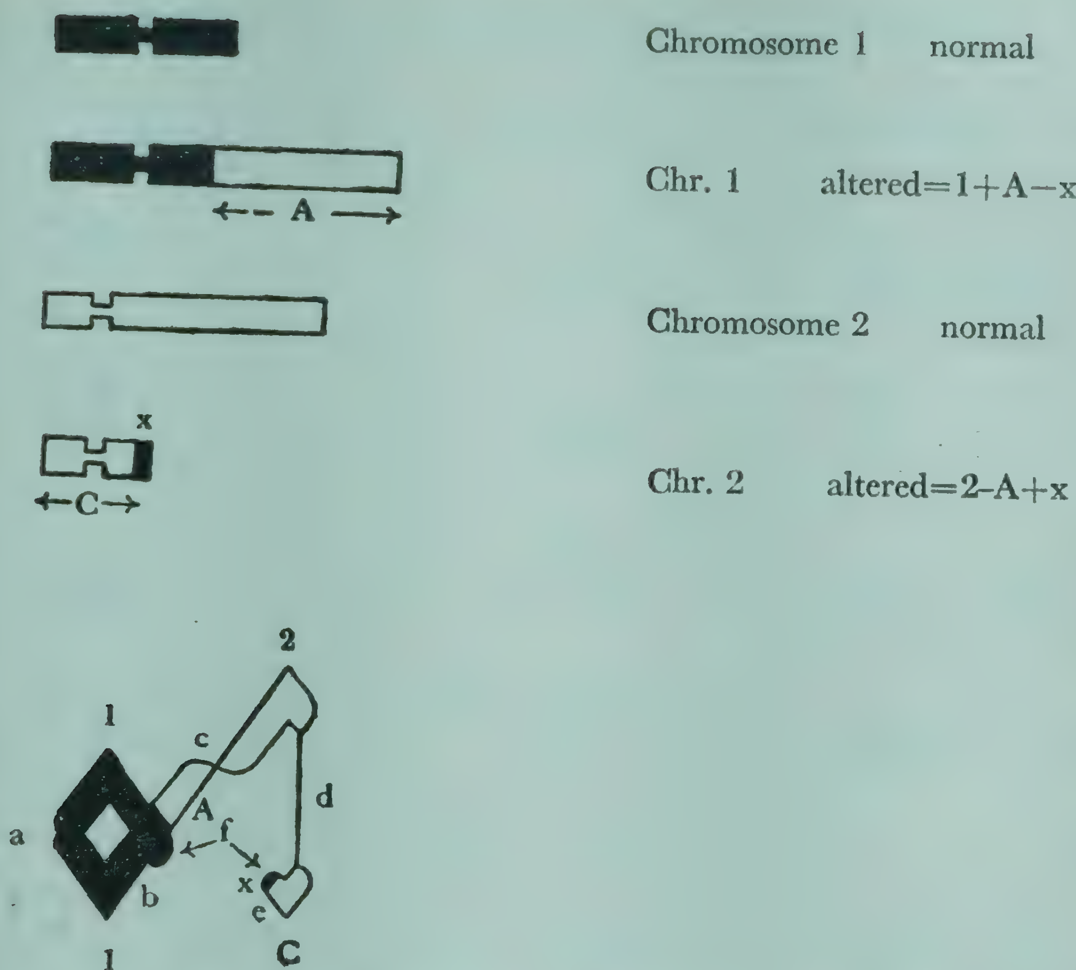


Fig. 34. Chromosome structure and the expected first metaphase configuration in reciprocal translocation heterozygotes like the *hirsutum* plant, 2 B-1. (from Menzel and Brown, 1952a).

deficiency—duplication genotypes was recovered from the translocation heterozygotes.

In backcrosses of the translocation heterozygotes to normal plants, it was found that female gametes resulting from disjunction or numerically equal (2:2)non-disjunction functioned nearly as frequently as expected on the basis of the cytological estimate made from the study of pairing and orientation of chromosomes at first metaphase during microsporogenesis of the heterozygous parent. Only one of the possible four different types of numerically unequal (3:1) non-disjunctional female gametes functioned in backcrosses of the translocation heterozygote to the normal; the remaining types were recovered in the selfed progenies of the translocation heterozygote or of the deficiency heterozygote (2n-C-x), monosomic for 'C' the centromere region and short arm of chromosome 2 and also for the 'x' segment of chromosome 1 (Table 70). It was considered possible that the numerically unequal non-disjunctional gametes suffer from some selective disadvantage which reduces their rate of recovery. The non-disjunctional heterozygous complexes obtained in the cross, (translocation heterozygote x normal), gave on selfing some more types of duplication deficiency offspring. The various deficiency-duplication derivatives are listed in Table 70.

TABLE 70. DEFICIENCY-DUPLICATION DERIVATIVES FROM THE TRANSLOCATION HETEROZYGOTE, 2B-1 IN *hirsutum* COTTON

	Chromosome constitution 24 II +	Genotype (=No. of chromosomes)	Indentifying configuration at first metaphase
1.	1 (Chr. 1 normal) +1 (Chr. 1 altered) +2 (Chr. 2 normal)	$2n$+A-x (= 52)	
2.	2 (Chr. 1 normal) +1 (Chr. 2 normal) +1 (Chr. 2 altered)	$2n$—A+x (= 52)	
3.	1 (Chr. 1 normal) +1 (Chr. 1 altered) +1 (Chr. 2 normal	$2n$—C-x (= 51)	
4.	2 (Chr. 1 normal) +1 (Chr. 2 normal)	$2n$—Chr. 2 normal (= 51)	
5.	1 (Chr. 1 normal) +1 (Chr. 1 altered) +2 (Chr. 2 normal) +1 (Chr. 2 altered)	$2n$+A+C (= 53)	
6.	2 (Chr. 1 normal) +2 (Chr. 2 normal) +1 (Chr. 2 altered)	$2n$+C+x (= 53)	
7.*	2 (Chr. 1 normal) +2 (Chr. 2 normal) +2 (Chr. 2 altered)	$2n$+2C+2x (= 54)	
8.	2 (Chr. 1 altered) +2 (Chr. 2 normal)	$2n$+2A−2x (= 52)	
9.	2 (Chr. 1 altered) +1 (Chr. 2 normal)	$2n$+A−C−2x (= 51)	
10.	2 (Chr. 1 altered) +2 (Chr. 2 normal) +1 (Chr. 2 altered)	$2n$+2A+C−x (= 53)	

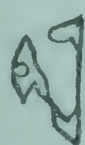
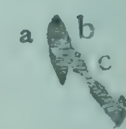
* Type not recovered.

The recovery of $2n+2A—2x$ and $2n+A—C—2x$ plants in the selfed progeny of the plant $2n—C—x$ demonstrated for the first time in cotton, the pollen transmission of small deficiency and its recovery in the homozygous condition. This deficiency is of a size to render plausible its classification as a cryptic structural change (see Stephens, 1950b), since its presence or absence could not be detected except by inference at the meiotic stages. Both deficiencies and duplications for C, A and x were functional in the ovules, while duplications of A, and probably also of C and x, were pollen viable. Menzel and Brown (1952a) point out that no case has previously been reported in plants in which the arrary of unbalanced complexes approaches the theoretical possibilities as closely as in the present case.

In the translocation heterozygote and in derivatives belonging to the classes $2n+A$ and $2n—C$ (Table 70), which were heterozygous for 'chromosomes 1 altered', the interstitial chiasma proximal to 'A' clearly failed to terminalize past the point of translocation. Even when the 'A' arm was not paired with 'chromosome 2 normal,' a heteromorphic bivalent with one chiasma in each arm could often be identified by the long, single A arm projecting beyond the chiasma (In cells in which no chiasma was present proximal to 'A', the point of attachment was usually marked by a slight constriction or faintly stained region). Failure of the chiasma to terminalize in heterozygotes for 'chromosome 1 altered' was probably not due to mechanical difficulties inherent in the unequal length of the paired arms, or to change of homology (*cf.* Darlington, 1937, p. 510), because terminalization also failed in plants of the classes, $2n+2A—2x$, $2n+A—C—2x$ and $2n+2A+C—x$ (Table 70), which were homozygous for 'chromosome 1 altered'. It was, therefore, inferred that the region of breakage and attachment of 'A' in chromosome 1 serves to prevent premetaphase terminalization of chiasmata proximal to it. It followed, therefore, that not more than one chiasma is characteristic of the arm at prophase, since no more than one metaphase chiasma was ever seen proximal to 'A'. What is true for one arm of chromosome 1 is, according to Menzel and Brown (1952a), probably true for other arms of the other chromosomes of *Gossypium*. The problem of whether the single terminal or nearly terminal chiasma per arm characteristic or metaphase bivalents in the genus represented a low original chiasma frequency, or a well advanced terminalization could not be tackled earlier because, in *Gossypium*, prophase studies are unfavourable for direct investigation, and no three-point gene linkage groups have yet been available for an estimate of double cross-over frequencies. Cytological study of the translocation heterozygote 2B-1 and some of its derivatives, has probably given the right answer to this long standing problem.

Menzel (1955) has determined the genom affinities of the two chromosomes involved in the 2B-1 translocation in *hirsutum* cotton. The derivative, $2n+2A—2x$ (Table 70), was crossed with *raimondii* (D_5). The diploid gamete

contained one altered chromosome 1 and one normal chromosome 2. According to the genom affinities of these chromosomes, the configurations to be expected during meiosis of the triploid hybrid were as follows.

	Condition			
	1	2	3	4
Chromosome 1 in genom :	D_h	A_h	A_h	D_h
Chromosome 2 in genom :	D_h	A_h	D_h	A_h
First metaphase configurations	1 IV, 11 II, 13 I	14 II	1 III 12 II 12 I	1 III 12 II 12 I
Identifying configurations		 Large II		

Of the above four theoretically expected identifying configurations only the fourth type was actually obtained. It was, therefore, clear that chromosome 1 is in the D_h genom and chromosome 2 in the A_h genom. The translocation trivalent figure could be distinguished from that due to intergenomic (D_h D_5 A_h) association because of the presence of the interstitial chiasma proximal to the 'A' segment in the former case. If intergenomic pairing in this particular hybrid had involved the chromosome 1 of the D genom, a quadrivalent figure should have been noticed. Since no such quadrivalent was observed, it was inferred that probably it does not pair with any A_h chromosome or it does so very infrequently.

The translocation trivalent in the hybrid ($2n+2A—2x \times$ *raimondii*) is similar to that in $2n-C—x$ derivative (Table 70). Normal chromosome 1 in the former case belongs to the D_5 genom whereas in the latter case it belongs to the D genom. Chiasma frequency studies at positions a, b, and c of the configuration revealed that when a D_5 chromosome 1 was substituted for the normal D_h chromosome 1 in the configuration, chiasmata were reduced significantly in the 'right' arm at position 'b' and increased significantly at position 'c' between the translocated 'A' and the normal arms of chromosome 2. This, according to Menzel (1955), suggested that there is some interference or competition between 'b' and 'c' in the 2B-1 translocation heterozygote. According to her, this interference got reduced as a consequence of the lower chiasma frequency proximal to the point of interchange

in the 'right' arm when a D_5 and a D_h chromosome 1 were present together and simultaneously chiasma formation at 'c' rose accordingly. It was, therefore, inferred that D_5 chromosome 1 differs in some way from the D_h chromosome 1 in the 'right' arm. The difference is in the direction of less frequent chiasma formation when the two are present together. There was no decrease in chiasma frequency at 'a' in the left arms of chromosome 1; it was doubted whether this *lack* of difference between the D_5 and D_h left arms of chromosome 1 was real, or only apparent because of a lack of competition. The pertinent conclusion from the data assembled seemed to be that chromosome 1 of D_5 is not perfectly homologous with chromosome 1 of D_h (Menzel, 1955). In a formal sense, the data were considered to be evidence for cryptic structural differences between chromosomes of *hirsutum* and *raimondii*, although the real nature of differences continued to be obscure. On the assumption that chiasmata represent cross overs, it was concluded, as Stephens (1949) had suggested, that the effect of the differentiation, where the two species are combined in a hybrid, is to reduce crossing over in the chromosome segments concerned, with consequent tendency of the parental characteristics determined by the genes on those segments to remain more tightly linked than would be expected within either species (Menzel, 1955). It was further suggested that it should be possible to test in a similar way the differentiation of each of the arms of each of the D_h chromosomes from its homologues in D_5 and in several other D genoms. It was considered not unlikely that such differences as to exist between different D genoms may be unevenly distributed along the various chromosome arms.

It was not feasible to compare chromosome 2 of 2B-1 translocation directly with its homologue in the A genom in a triploid F_1 hybrid because: (*i*) hybrids between *hirsutum* and the A genom species are very difficult to obtain; and (*ii*) A_1, A_2 and A_h genoms differ in the end arrangement of some of their chromosomes, so that $(AD)_1A_1$ hybrids form 9II, 2IV and $(AD)_1$ A_2 hybrids from 8II, 1IV, 1VI instead of 13II (Fig. 32). Hence analysis of newly rearranged chromosomes in *hirsutum* by means of such hybrids is expected to be complicated by the associations of IV and VI already present. A fertile 52-chromosome derivative from Amph. 6*x*-(*hirsutum* x *herbaceum*) backcrossed repeatedly to *hirsutum* retained only one of the translocation rings shown by the F_1 (*hirsutum* x *herbaceum*). This derivative was, therefore, crossed with the plant homozygous for the 2B-1 end arrangement (Menzel, 1955). Two out of 10 F_1 hybrids obtained showed VI in most of their pollen mother cells indicating thereby that chromosome 2 is one of the four A_h chromosomes which differ in end arrangement from the chromosomes of A_1. These two plants, in all probability, received two chromosomes with the A_1 end arrangement from the tetraploid derivative parent. It was assumed that chromosome 2 in the 2B-1 translocation is chromosome 3-5 of the A genom (see Fig. 32 after Menzel and Brown, 1954)

and that arm 5 is the translocation arm 'A'. The configurations were expected to be the same regardless of which of the eight—Nos. 3 to 10—in Fig. 32 arms were actually involved. The D_h chromosome 1 was designated 27-28 for convenience, with end 28 corresponding to the short, non-pairing translocated segment 'x'.

The remaining eight F_1 hybrids showed configurations conforming with the pairing expected if various types of balanced or deficiency-duplication eggs had been fertilized as shown in Table 71. Menzel (1955) has thus produced concrete evidence for the recovery of some of the deficiency-duplications from the A genom multivalent complexes.

TABLE 71. F_1 (A 4x DERIVATIVE FROM *hirsutum-herbaceum* HYBRID, RETAINING ONE OF THE TRANSLOCATION RINGS IN THE A GENOM) x THE TRANSLOCATION 2B-1 HOMOZYGOTE

End arrangements of three of the thirteen gametic chromosomes	Sperms: 27-5 (chromosome 1 altered) 3-28 (chromosome 2 altered) 4-6 (in A_h genom)		
Eggs	**Genotype of eggs**	**Identifying maximum mataphase I associations in F_1's**	**No. of F_1's obtained**
1. 27-28 (chromosome 1 normal, D_h genom) 3-5 (chromosome 2 normal, *ex* A_h genom) 4-6 (*ex* A_h genom)	Balanced	1 IV	5
2. 27-28 (Chr. 1 normal, D_h) 3-4 (*ex* A_1) 5-6 (*ex* A_1)	"	1 VI	2
3. 27-28 (Chr. 1 normal, D_h) 3-5 (*ex* A_h) 5-6 (*ex* A_1)	Duplication 5 Deficiency 4	1 VI	1
4. 27-28 (Chr. 1 normal, D_h) 5-6 (*ex* A_1) 4-6 (*ex* A_h)	Duplication 6 Deficiency 3	1 V + 1 I	—
5. 27-28 (Chr. 1 normal, D_h) 3-4 (*ex* A_1) 4-6 (*ex* A_h)	Duplication 4 Deficiency 5	1 IV+1 II	2
6. 27-28 (Chr. 1 normal, D_h) 3-4 (*ex* A_1) 3-5 (*ex* A_h)	Duplication 3 Deficiency 6	1 VI	—
			10

USE OF ANEUPLOIDS AND CHROMOSOME STRUCTURE VARIANTS IN GENETIC ANALYSIS

Several pairs of genes are known to be linked in different *Gossypium* species, but these have not been assigned to particular chromosomes. At present, an attack on this problem with regard to the **Hirsuta** species, is being made by

studying the cytogenetical behaviour of trisomic, tetrasomic, monosomic and translocation lines.

In some F_2 populations of *hirsutum* x *barbadense* hybrids, 15:1 normal/asynaptic plants are recovered (Beasley and Brown, 1942). It was suggested that this reduced metaphase pairing is controlled by loci on at least two chromosomes, of which one is probably in the A and the other in the D genom; the double recessive condition results in asynapsis. An asynaptic plant was also obtained in the progeny of a monosomic possessing quadrivalent (Brown, 1948). The parent variety was Coker 100 (*hirsutum*), which in hybridisation with Bleakhall (*barbadense*) gives asynaptic plants in F_2. The occurrence of asynapsis in the progeny of this monosomic plant was suggested to be due to quadrivalency and the concomitant chromosome segregation leading to triplicate or quadruplicate dosage of the recessive asynapsis determinant in *hirsutum*. Tetrasomaty of one recessive locus was considered to be responsible for reduced chromosome pairing in the line, K. 24 derived from Coker 100 (Menzel and Brown, 1955). The postulate, regarding the dosage effect of the recessive genes governing reduced synapsis was tested by Menzel and Brown (1955) in an experiment designed for the purpose. Trisomic derivative from K. 24 was crossed with the doubled Bleakhall haploid. According to the hypothesis genetic constitution of the parents would be $\mathbf{a}_1\ \mathbf{a}_1\ \mathbf{a}_1\ \mathbf{A}_2\ \mathbf{A}_2$ and $A_1\ A_1\ \mathbf{a}_2\ \mathbf{a}_2$, respectively. The trisomic F_1 would be $\mathbf{a}_1\ \mathbf{a}_1\ A_1\ A_2\ \mathbf{a}_2$. This F_1 on backcrossing to *barbadense* parent was expected to give some trisomic plants, one-sixth of which would have the genotype $\mathbf{A}_1\ \mathbf{a}_1\ \mathbf{a}_1\ \mathbf{a}_2\ \mathbf{a}_2$ and would show a reduced chiasma frequency. All the 42-chromosome plants in the backcross generation were expected to have normal pairing since they could not have inherited more than three recessive genes. Actually, however, half of the disomics and 5/6ths of the trisomics showed a slightly to markedly reduced chiasma frequency. The postulate, therefore, appeared to be obviously in error (Menzel and Brown, 1955).

More critical studies of the frequency of chiasmata (that is, paired bivalent arms) per potential bivalent in F_2 progenies and backcrosses to *barbadense* and to disomic lines from K24. were made from both disomic and trisomic F_1's of the cross (trisomic *ex* K 24 x doubled Bleakhall haploid). Progenies from the two kinds of F_1's and their backcrosses to *hirsutum* averaged 1·95 to 1·8 chiasmata per chromosome pair (a maximum of 2·0 is possible with the method of calculation used). In the F_2, about 1/16th were sterile and showed a chiasma frequency below 0·9. Chiasma frequency in about double this proportion of plants fell below 1·8, the lower range of the parents, and extended up to 1·3. The plants of this second category were partly fertile. Rest of the plants showed normal pairing and were fully fertile.

In the backcross to *barbadense*, chiasma frequency ranged from 1·95 to 0·1; about 1/4th of the plants having a chiasma frequency below 1·8.

The hypothesis given earlier for the behaviour of asynapsis in *hirsutum-barbadense* hybrids was, therefore, modified as follows:

Let the *hirsutum* parent be $\mathbf{a_1 a_1 A_2 A_2}$ and the *barbadense* parent $\mathbf{A_1 A_1 a_2 a_2}$.

Let both $\mathbf{a_1}$ and $\mathbf{a_2}$ be necessary for a reduction in metaphase chiasma frequency.

Let $\mathbf{a_2}$ be completely recessive to $\mathbf{A_2}$, but let $\mathbf{a_1}$ be incompletely recessive to $\mathbf{A_1}$, giving an intermediate expression in the heterozygote in the presence of $\mathbf{a_2 a_2}$.

On the basis of this modified hypothesis, the F_1's under consideration and their backcross to *hirsutum* should show normal pairing, since every plant would carry $\mathbf{A_2}$. The F_2 should show a 13:2:1 ratio with $\mathbf{A_1 a_1 a_2 a_2}$ having slight and $\mathbf{a_1 a_1 a_2 a_2}$ marked reduction in chiasma frequency. The observed data showed a good fit to the expectations on the basis of the modified hypothesis.

In the F_2 the plants with reduced pairing were sharply divided into two groups: sterile plants and partly sterile plants. The plants with reduced pairing in the backcross to *barbadense*, however, showed a more or less continuous and wide range of chiasma frequencies. This was stated to be explicable on the assumption that modifiers from *barbadense* act to shift the expression of a_1 in the direction of greater dominance. In the backcross, even plants with very low chiasma frequencies at the time of sampling were not completely sterile, suggesting that they sometimes had better metaphase pairing than on the day of sampling. Genotype heterozygous for a_1 was, therefore, considered to be probably more sensitive to fluctuations in temperature and moisture than is the double recessive (Menzel and Brown, 1955).

Certain cross compatibility relationships of *gossypioides* in interspecific hybridization have been interpreted on the basis of the above hypothesis concerning reduced synapsis in *hirsutum-barbadense* hybridization (Menzel and Brown, 1955). The good pairing of the D genom chromosomes in *hirsutum-gossypioides* cross and the lack of it in *barbadense-gossypioides* (Table 61) was explained on the assumption that one of the factors ($\mathbf{a_1}$) was located in the D genom and the other ($\mathbf{a_2}$) in the A genom. Assuming further that D_6 carried $\mathbf{a_1}$, genotype of *hirsutum-gossypioides* F_1 was put as $\mathbf{a_1 a_1 A_2}$ and was expected to show normal pairing. The *barbadense-gossypioides* F_1, on the contrary, was genotypically $\mathbf{A_1 a_1 a_2}$. It was expected to show reduced chiasma frequency due to incomplete dominance of $\mathbf{A_1}$; the extreme degree of asynapsis actually observed was attributed to *barbadense* modifiers which shift the expression of $\mathbf{a_1}$ to dominance (Menzel and Brown, 1955).

Since other D genom species showed normal pairing of the homologues in crosses with **Hirsuta** species (Table 61), it was postulated that they carry the $\mathbf{A_1}$ allele rather than the $\mathbf{a_1}$ as in *gossypioides*. In F_2 progeny of Amph. (*arboreum* x *thurberi*) x *hirsutum*, normal and asynaptic plants have been obtained in the ratio of 15:1 (Bradford, 1954-unpubl., cited by Menzel and

Brown, 1955). It was, therefore, inferred that the *arboreum* ancestor of this F_2 carried a gene similar to or identical with $\mathbf{a_2}$ (Menzel and Brown, 1955). The recovery of asynaptics in selfed progenies derived from the cross *hirsutum* x Amph. (*arboreum* x *harknessii*) also suggested that *arboreum* carried $\mathbf{a_2}$ and *harknessii* $\mathbf{A_1}$ genes (Menzel and Brown, 1955).

Derivatives of the translocation heterozygote 2B-1 in *hirsutum* belonging to the classes $2n$–A + x and $2n$–C–x (Table 70) are deficiencies for complementary portions of chromosome two, whereas, the class $2n$-Chr. 2 (Table 70), is monosomic for the whole of the chromosome 2 (Menzel and Brown, 1952a). Considering that the first two types of lines would be useful in locating genes on known arms of chromosome 2, Menzel and Brown (1952a), used them in crosses with genetic markers. Of the five loci involved in their study none was situated on either arm of chromosome 2. This finding was corroborated by the results from the hybridization of the line monosomic for chromosome 2 with the same marker stock. Menzel and Brown (1952a) further tested if any one of the five genes under investigation was linked with the attached segment 'A' in chromosome 1 altered (Fig. 34). The gene for red plant colour appeared to be linked with this segment and hence was considered to be situated on chromosome 1 (This chromosome 1 was found to be a member of the D_h genom—Menzel 1955). Menzel and Brown (1952) point out that in practice deficiency and/or duplication types obtained by irradiation of cotton may prove both more easily recovered and more useful than the monosomics because some of the former types are likely to be transmitted with greater regularity and are expected to make it possible to determine concurrently the location of the genes and the particular region of the chromosome concerned. Certain derivatives of the radiation induced translocation 2B-1 have been used for comparing the chromosomal anatomy of *hirsutum* with that of its diploid relatives (Menzel, 1955). The translocation derivates also present attractive possibilities of a similar comparison in regard to genetic anatomy. Cytogenetic information of this sort is expected to have a considerable bearing on problems of transferrence of desirable characters from the diploid species to the **Hirsuta** cultigens (Menzel and Brown, 1952a).

Menzel (1955), in her studies on the translocation line 2B-1, obtained evidence for the functioning of duplications and deficiencies of at least two of the ten ends of the five differential chromosomes of the A_1 and A_h genoms (Figs. 32 and 34). She foresees the possibility of eventual analysis, in considerable detail, of both the dosage effects and genetic content of the differential A genom chromosomes, with the help of suitable translocation lines.

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Note : I.C.C.C. = Indian Central Cotton Committee.

I.C.G.R. = Indian Cotton Growing Review.

P. B. A. = Plant Breeding Abstracts.
(Commonwealth Bureau of Agriculture).

CHAPTER VIII

GENETICS

Extensive genetical investigations have been carried out in the genus *Gossypium* by several workers. Kearney (1930a) and Harland (1932c, 1939) have reviewed the results of earlier investigations and Knight (1954c) has abstracted the literature on the subject from 1900-50. Several genes governing the various characters in the genes have been discovered, a comprehensive list of which is appended to Knight's (1954c) abstract bibliography. This list of known genes is reproduced in Table 75.

Genetical investigations have not been restricted to intraspecific hybrid material, despite the incompatibility or sterility barriers met with in distant hybridization. These obstacles have been overcome or by-passed by employing techniques such as backcrossing, polyploidy and trispecies or multi-species hybridization. Genetic analysis has, therefore, been made in *Gossypium* material ranging from diploid to hexaploid level in its chromosome constitution. The findings are reviewed here, under the following heads:

1. Determinants for various plant characters.
2. Pleiotropy.
3. Linkage.
4. Comparative genetics and interspecific homologies between gene loci.
5. Inheritance in synthetic polyploids.
6. Determinants for cross incompatibility.

DETERMINANTS FOR VARIOUS PLANT CHARACTERS

GENERAL PLANT CHARACTERS

Habit. Leake and Ram Prasad (1914) crossed sympodial and monopodial types of cotton of the Old World with a view to studying the genetics of the length of the vegetative period using: (*i*) length of the vegetative zone expressed as percentage of main axis; and (*ii*) period taken for the appearance of first flower as the criteria. It was realised that these criteria were open to error, the former due to shedding of buds and latter due to the environmental effect. They noted that the F_1 between a monopodial and a sympodial type was not exactly intermediate between the two parents in matter of length of vegetative period, but was nearer to the early parent. The F_2 population formed a continuous series between the parental values. It was, however, noted that whereas the parental full sympodial type reappeared in the progeny, full monopodial type was never recovered. No factorial analysis of the data was possible.

Hutchinson (1936) studied the inheritance of node number (node from the base of the shoot at which the first sympodial branch appears) in five Old World cottons and found that all the F_2s transgressed the parental limits at the upper and/or the lower end of the frequency array. Very large differences in variance existed between the different F_2s but the size of the variance bore no relation to the magnitude of difference between parental means. Although the node number was found to be associated with three main factors, there were indications that many minor factors were operating.

Height. Hutchinson and Gadkari (1937) noted that the homozygous Punjab Hairy Lintless was dwarf and that this character, although a pleiotropic effect of lintlessness (**li**$_c$) behaved as a simple recessive, normal being fully dominant. The inheritance of the gene so far as lintlessness was concerned was 1:2:1.

Venkoba Rao and Ramchandran (1943) observed a bushy dwarf in *G. herbaceum* var. *acerifolium** (*herbaceum* race *wightianum*) which behaved as a simple recessive to normal plant, the latter being fully dominant. No gene symbol was assigned to it.

Balasubrahmanyan and Santhanam (1950a) studied the inheritance of four dwarf mutants, viz., Coimbatore dwarf, Anakapalle dwarf, Cocanada dwarf and 1767 dwarf, in *arboreum* race *indicum*. They found that all these dwarfs behaved as simple monogenic recessives to normal, the latter being fully dominant in F_1. They further found that, the same gene was involved in the Cocanada as well as 1767 dwarf. This gene was complementary to Anakapalle dwarf gene for production of normal plant. Homologies of Bushy dwarf (Venkoba Rao and Ramchandran, 1943) and Coimbatore dwarf could not be tested. Gene symbols **d**$_a$ and **d**$_b$ have been suggested for Anakapalle dwarf and Cocanada dwarf, respectively.

In New World cottons, Kearney (1930b) reported short branch in Pima cotton showing monohybrid inheritance without dominance. Hutchinson (1946a) reported a Columbian dwarf to be triple recessive when crossed with Upland and Sea Island cottons.

Chlorophyll Deficiency. Hutchinson and Bholanath (1938) reported a chlorophyll deficient seedling appearing in a cross between Malvi 9 (*arboreum* race *bengalense*) and a race *cernuum* type. It was found to be purple coloured and monogenic recessive to normal; the latter being fully dominant. Hutchinson and Silow (1939) suggested gene symbols, **Chl-chl** for green-chlorophyll deficient pair.

Yellow Seedling Lethal: Yu (1939a) reported on the frequent occurrence of yellow seedling in the Old World cottons of China. He found it to be controlled by a single recessive gene; the homozygous yellow seedling being lethal. No gene symbol has been assigned to it.

Patel, Munshi and Patel (1947) described a similar mutation in *G. herba-*

ceum race *wightianum*. It was a simple recessive, the homozygous seedling having yellowish cotyledons which slowly turned whitish and papery. It died after 10 or 12 days due to lack of chlorophyll. Its linkage relationship with anthocyanin pigmentation was different from that of the similar mutant reported by Yu (1939a).

Virescent Bud (Vegetative Bud): Yu (1939b) described a case where the bud and its enfolding leaves are always yellowish green in colour. Its cotyledons are virescent when first expanding, gradually changing to normal green by the time true leaves, also virescent, begin to appear. As the terminal bud extends upwards, it remains virescent but the lower maturing leaves turn green. There are always virescent young leaves at the top of the mutant plant as long as it lives. Studies carried out showed that this virescent bud character was due to a single gene, the normal green being fully dominant. The gene has been assigned the symbol $\mathbf{v}_1$ as against $\mathbf{V}_1$ normal green.

Yu (1941) reported the occurrence of three more virescent mutants, viz., $\mathbf{v}_2$, $\mathbf{v}_3$ and $\mathbf{v}_4$ which occurred in pure lines of Old World cottons. These virescent mutants were simple monogenic in inheritance, normal being fully dominant. It was observed that these four genes are independently assorted and that $\mathbf{v}_1$ and $\mathbf{v}_2$ are complementary.

Chlorophyll Deficiency, X-ray Induced: Ramanathan and Balasubrahmanyan (1938) reported the occurrence of two chlorophyll deficient mutants in two varieties of cotton treated with X-rays: 'Albino' in a strain of *G. herbaceum* race *wightianum* and 'Xantha' in *G. arboreum* race *indicum*. Balasubrahmanyan (1947) found that both these chlorophyll deficient types behaved as simple monogenic recessives, normal being completely dominant. Both these genes were independent of each other and their homologies with other known deficient types have not been worked out. Genic symbols $\mathbf{chl}_1$ and $\mathbf{chl}_2$ have been proposed for 'Albino' and 'Xantha', respectively. It was pointed out that descriptions of chlorophyll deficients given by Hutchinson and Bholanath (1938) and Yu (1939a) agree closely with the $\mathbf{chl}_2$ effect and that the 'Albino' type $\mathbf{chl}_1$ appears to be new and different.

In New World cottons, work of Stroman and Mahoney (1925) and Harland (1934b) shows the presence of two duplicate genes $\mathbf{chl}_1$ and $\mathbf{chl}_2$ (Hutchinson and Silow, 1939) responsible for the occurrence of chlorophyll deficiency. Similarly a virescent yellow, simple monogenic recessive (V-v) was noted by Texas workers in *G. hirsutum*. Furthermore, Horlacher and Killough (1932a, b) reported the occurrence of a recessive yellow in American cotton as a result of irradiation.

Cluster (Boll Bearing). Patel, Munshi and Patel (1946) reported the occurrence of a 'cluster' habit in a mutant noticed in 1027A L. F. (*herbaceum* race *wightianum*). It was characterised by one noded fruiting branch ending in two flower buds, one of which usually aborted. When, however, both developed it appeared as if two bolls had arisen from the same point. It

had considerable secondary growth in the form of small leaves. Flower size was small and bolls roundish. This character was found to be a simple recessive, the normal being fully dominant. The gene symbol assigned to it is **cl**.

A highly clustered type called 'whorled' was discovered in *herbaceum* by Chavda and Patel (1954). In addition it had two to three loculed bolls. Bhat and Desai (1956) have reported that cluster and whorled are characters governed by complementary loci.

Occurrence of cluster habit due to a single recessive gene, $\mathbf{chl_1}$ has been reported by Thadani (1923) in the New World cottons. Kearney (1930b) described a type of Egyptian cotton in which the fruiting branches are reduced to a single internode and in which two or three branches appear often at the same node. On crossing with normal, the F_1 was intermediate and F_2 gave short branch, intermediate and long branch phenotypes in 1:2:1 ratio. The gene symbol for short branch is **sh**.

Crinkled Leaves. Balasubrahmanyan and Santhanam (1951a) have reported the occurrence of a crinkled mutant in inter-racial (*indicum-cernuum*) hybrid cultures of *arboreum*. The leaves were small and narrow with chlorotic patches, but otherwise the type made good growth. Its crosses with normal plant gave an incomplete dominance in F_1 and segregation of normal, F_1 like, and crinkled plants occurred in F_2 in 1:2:1 ratio. Backcross of the F_1 to crinkled gave the expected 1:1 ratio. The symbol proposed for the gene is **cr (cra)**.

In New World species of *Gossypium* very detailed genetic investigations have been carried out on this character since it was first noted in Sea Island. Harland and Atteck (1941b) demonstrated the existence of normal alleles of crinkled mutant gene in different species which differ in dominance potency. Hutchinson (1946b) showed that an allelomorph series of not less than five members existed at the **Cr** locus in New World cottons. Of these, two ($\mathbf{Cr^B}$ and $\mathbf{Cr^H}$) are normals differing only in their heterozygotes with crinkled $\mathbf{Cr^D}$. 'Full normal' ($\mathbf{Cr^B}$) is carried by most strains of *barbadense* and is rare in *hirsutum*. Low normal ($\mathbf{Cr^H}$) is carried by most strains of *hirsutum* and is rare in *barbadense*. Crinkled dwarf, $\mathbf{Cr^D}$, gives rise to leaf abnormality in which vein growth fails to keep pace with lamina development. It arises by mutation fairly frequently in Sea Island and Egyptian cotton and the reverse mutation has also occurred. Rugose (Indon crinkled, $\mathbf{Cr^I}$), and contorta $\mathbf{Cr^6}$ gives rise to abnormalities in which lamina expansion fails to keep pace with vein growth. Contorta is responsible for a much greater degree of abnormality than rugose. Rugose has appeared in *hirsutum* only once so far but contorta arises fairly frequently in two commercial strains of Sea Island, Superfine V. 46 and M.S.I.

Curly Leaf. Yu (1939b) described a curly leaf mutant in Old World cotton

in which leaf margin curls upwards and inwards. The curly character appeared one week after germination. The petals of curly plant were nearly one half their normal size; the bolls and seeds were also smaller. It was found to be a simple monogenic recessive, normal being fully dominant in F_1. The gene symbol proposed is **cu**.

Bhat and Khattar (1953) recorded the occurrence of a similar mutant having up-curled leaves in *herbaceum* race *wightianum*. This character was also controlled by a single recessive gene. Its homology with **cu** has not been tested. Microscopic examination revealed that the palisade cells in the curled leaf are narrower and more densely packed; the lint fibres were appreciably thinner.

Crumpled Leaves. Hutchinson (1932a) described a genetical type called 'crumpled' in a progeny of cross between *arboreum* race *soudanense*, a wild cotton of the Sudan, and *arboreum* var. *sanguinea**. It was semi-sterile with all leaves crumpled. He showed that the crumpling was due to the interaction of two complementary factors **(A) Cpa** and **(B) Cpb**. Investigating the distribution of **A** and **B**, he found that **A** was carried by only two strains of *soudanense*. Most of the other cultivated types and *G. stocksii* carried **B**.

Later Bholanath and Govande (1943) showed that Rozi and Gaorani cottons (*arboreum* race *indicum*) of the Deccan India carry the crumpling genes **A** and **B**, respectively. In a cross of Rozi x Gaorani 6, Bhat and Patel (1957) obtained normal and Crumpled F_1 hybrids in the ratio of either 3:1 or 1:1 from which the authors inferred that the **B** gene in the male parent comprises two complementary loci. Segregation obtained in backcrosses of the hybrid to Gaorani 6 supported the compound nature of this gene. Earlier, Stephens (1950a) had examined the complementary crumpled mechanism in Old World cottons. It showed striking genetic and phenotypic similarity to the corky mechanism. Stephens, therefore, suggested that the two complexes have a similar pseudo-allelic basis. Inspite of their close similarity there is, as yet, no critical evidence that crumpled and corky are duplicates located in the A and the D genoms, respectively, of *Gossypium*.

Hairiness. Inheritance of spinnable (lint) and non-spinnable (fuzz) hairs on the seed surface will be dealt with later on. Here it is proposed to deal only with the hairiness of other parts of the plant, although this and other characteristics such as seed fuzz, lint index, corolla hairiness, calyx hairniness, etc., are all part of one general hairiness mechanism.

Completely glabrous waxy bodied lintless mutants were noticed by different workers in Old World cottons and their inheritance was studied by Afzal and Hutchinson (1933); and Hutchinson and Gadkari (1937). He latter found that the glabrous waxy plant body and lintless nature were due to a single recessive gene either **ha** or **hb**, the normal hairy linted being fully dominant. The glabrous body and lintlessness were pleiotropic effect of the same gene.

The two genes were found to be complementary; the F_1 being fully hairy and linted and the F_2 giving hairy linted and glabrous lintless in 9:7 ratio.

Ramiah and Paranjpe (1944), found that stellate hairs of a lintless mutant, **li$_d$** in *herbaceum* were controlled by a single recessive gene, **h^{vi}**.

Among New World cottons, both glabrous and hairy dorms are present in *barbadense* and *hirsutum* whereas *tomentosum* is invariably covered with a thick *tomentum* of short hairs. Balls (1912), McLenden (1912), Harland (1915), Kearney (1923a) and Kulkarni and Khadilkar (1929) studied crosses between different glabrous types of *barbadense* and hairy types of *hirsutum*. They mostly found F_1 glabrous or incompletely hairy, more on glabrous side. The F_2 showed blending inheritance making facterial analysis of data difficult. Balls (1912), however, reported that glabrous and hirsute occurred in 3:1 ratio. Harland (1939) indicated that the hairiness on the edge of the thickened portion of the base of the corolla was associated with segregation of fuzzy and naked seeded nature.

The hairiness in *tomentosum* was found to be due to $\mathbf{H_2}$ ($\mathbf{H^{TO}}$) in whose presence the middle lobe of the leaf became shorter (Knight and Sadd, 1953; Harland, 1939).

In *hirsutum*, a line possessing dense pubescence on the external surfaces of plants including stems, bracts, bolls and even floral petals together with very short fibres was reported to differ from glabrous normal linted types by a single gene (Simpson, 1947). The pilose condition and short lint were considered to be pleiotropic effects of the same gene. Knight and Sadd (1953), and Knight (1955) have reported this gene to be identical with $\mathbf{H_2}$ of *tomentosum*.

In Tanguis cottons pronounced development of hairiness on the back of the leaf occurs. On crossing with glabrous Sea Island, this hairiness behaves in a simple mendelian way giving in F_2 very hairy, intermediate hairy and smooth phenotypes in the ratio 1:2:1. This hairiness factor of Tanguis is designated $\mathbf{H_1}$ ($\mathbf{H^{TA}}$ or $\mathbf{H^B}$) (Harland, 1944; Knight, 1954b,d).

Sterility. Hutchinson and Gadkari (1935) studied the genetics of a sterile rogue in Million Dollar (*arboreum* race *sinense*) and found it to be due to a single recessive gene, normal fertile being fully dominant. The sterility was equal on both male and female side. Ramiah and Gadkari (1941) later reported that this sterility was due to asynapsis. The gene for the same has been given the symbol, **stp**.

Iyengar (1934) described a case of female sterility in *herbaceum* wherein the style and stigma of the flower were flattened and abortive; Vijayaraghavan, Iyengar and Venkoba Rao (1936) studying the inheritance of the same found it to be due to a single recessive gene, **stg**, the normal being fully dominant.

Balasubrahmanyan and Santhanam (1951b) described a case of male sterility, where the mutant type had staminodes and set normal bolls on being dusted with foreign pollen. They called it 'pistillate' and found the same

to be due to a single recessive gene, designated **pte**, normal **pte** being fully dominant.

ANTHOCYANIN COLOURATION

The genetics of the presence or absence and degree of intensity of anthocyanin colouration in the different vegetative parts of the plant and flower has been studied, by several workers.

Leake (1911a, b) and Leake and Ram Prasad (1912b, 1914) studied the inheritance of presence or absence of coloured spot on petals. Their studies, however, were of a preliminary nature.

In Old World cottons, Hutchinson (1932b) found six types of anthocyanin distribution in the plant body and lined up the results of earlier workers in a multiple allelomorph series of six genes, viz., $\mathbf{R}$, $\mathbf{R}^1$, $\mathbf{R}^c$, $\mathbf{R}^s$, $\mathbf{r}^o$, $\mathbf{r}^g$, limiting distribution of colour into progressively fewer areas. These types were called full red, red leaf, red calyx, red spot, spotless and ghost spot, respectively.

Harland (1935a) established the homology of this series with $\mathbf{R}_2$ series of the tetraploid New World cottons and as such Hutchinson and Silow (1939) introduced the same numerical subscript for this series as well.

Subsequently, Hutchinson and Ghose (1937c) reported a seventh member of the series, $\mathbf{R}^o{}_2$ which was similar to $\mathbf{R}_2{}^L$ vegetatively but like $\mathbf{r}^o$ in flower spot, and in this respect complementary to $\mathbf{r}^g$.

They also indicated the presence of a 'spot reducer' gene which was probably further assisted in its action by yet another factor.

Silow and Yu (1942) studying the anthocyanin pattern in Old World cottons in great detail inferred that the various expressions of anthocyanin in the vegetative parts of cotton plant fall broadly into two types which may be characterised as 'intense' or 'dilute' reds. The former have an intense purplish red colouration which develops to some extent even in absence of sunlight. The 'dilute' red shows a red flush which is never so intense nor so uniformly distributed on the particular organs affected as in the intense class, and which for its complete expression is dependent upon direct exposure to bright sun. Apart from variations due to environmental factor like shading both the types exhibit differences in intensity, characteristic of the main allele or caused by minor modifiers. The vast majority of Old World cotton plants have a red spotted flower and a red stem on which anthocyanin of a dilute type is clearly discernible with the naked eye. For convenience of description the commonest type of vegetative expression is termed 'sun red' because it is so dependent upon exposure to sun for its expression. A lower grade of stem anthocyanin may be recognised as a fairly distinctive type in some very occasional examples of common red petal spot type and the spotless type which Hutchinson described. These types appear almost green to the naked eye even when grown in intense sunlight, but have a 'nigropunctate' stem due to anthocyanin pigmentation in the cells surrounding the

TABLE 72. ANTHOCYANIN PATTERN

	Type	Symbols	Petals			Anthers	
			Spot	Lamina	Edge	Filaments	Lobes
Intense Red	Full red, spotted	$\mathbf{R}_2^{RS}$	Red	Fully red		+	+
	Red Margin, spotted	($\mathbf{R}_2^{MO}$), $\mathbf{R}_2^{MS}$	Red	Red Margin		+	0
	Red Margin, spotless	($\mathbf{R}_2^{NO}$), $\mathbf{R}_2^{MO}$	Spotless	Red Margin		Slight	0
	Red Vein, spotted	$\mathbf{R}_2^{VS}$	Red	Not red	Tinged	+	0
	Red Vein, spotless	($\mathbf{R}_2^{WO}$), $\mathbf{R}_2^{VO}$	Spotless	Not red	,,	0	0
	Red Leaf, spotted	$\mathbf{R}_2^{LS}$	Red	,,	,,	+	0
	Red Calyx, spotted	$\mathbf{R}_2^{CS}$	Red	,,	,,	+++	++
Dilute Red	Sun-red, spotted	($\mathbf{R}_2^{AS}$), $\mathbf{R}_2^{ASA}$	Red	,,	,,	+	0
	Sun-red, spotless	$\mathbf{R}_2^{BO}$	Spotless	,,	,,	0	0
	Thumb-nail red, spotted	$\mathbf{R}_2^{DS}$	Red	,,	,,	++	0
	Thumb-nail red, spotless	($\mathbf{R}_2^{EO}$), $\mathbf{R}_2^{DO}$	Spotless	,,	,,	0	0
Green	Green Stem, spotless	$\mathbf{R}_2^{FO}$	Spotless	,,	,,	0	0
	Green Stem tinged ghost	$\mathbf{R}_2^{TS}$	Tinged ghost	,,	Not tinged	0	0
	Green Stem, ghost	$\mathbf{R}_2^{OS}$	Ghost	,,	,,	0	0

(after Silow and Yu, 1942)

IN OLD WORLD COTTON

Calyx		Bract		Leaf				Stem	Boll
Intensity	Extent (area)	Inner surface	Outer surface	Lamina	Veins	Pulvinus spot	Petiole		
++	½-2/3	+	+	+++	++	+++	+++	++	++
+	¼-1/3	++	++	+	+	+++	++	++	++
+++	¾	+++++	+++	++++	+++	+++	+++	++	++
+	Entire	++	+	++	+++	+++	++	+	+
+++	Entire	++++	++	++++	++	+++	+++	++	++
+	Entire	+	+	+++++	0	+++	++	+	++
++++	Entire	+++	++	0	0	+	Sun-red	Sun-red	+++
0	0	0	Flush	0	0	+++	"	"	Flush
0	0	0	Trace	0	0	++	"	"	Flush
0	0	0	0	0	0	Trace	0	Thumb-nail	0
0	0	0	0	0	0	0	0	"	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

sub-epidermal oil glands. When the surface layers of stem are scraped with thumb-nail so that the glands are damaged and sap is expressed it is seen that the sap is strongly coloured with anthocyanin. The thumb-nail test affords a ready means of distinguishing types with a low level of anthocyanin development from pure green types which completely lack anthocyanin from all vegetative parts of the plant and whose oil glands are brownish green in colour. The former types are, therefore, called 'thumb-nail red'.

Superimposed upon the main grouping into green and red, and the intensity and distribution classes of the latter, is the separation into forms with or without red petal spot. Within the limitations imposed by such independent variables, 14 types were recognised by Silow and Yu (1942) and arranged in descending order of the extend and intensity of pigmentation. They summarised their distinguishing features which are reproduced in Table 72.

Ramiah and Bholanath (1944) described two more anthocyanin types in Asiatic cottons which fitted in the pattern of allelic series described by Silow and Yu (1942). They called them 'weak thumb-nail red-spotted' and 'green spotless-2, and assigned the symbols $\mathbf{R}_2^{GS}$ and $\mathbf{R}_2^{HO}$, respectively. $\mathbf{R}_2^{GS}$ differs from $\mathbf{R}_2^{DS}$ by the absence of anthocyanin in filaments which is present in the latter. $\mathbf{R}_2^{HO}$ differs from $\mathbf{R}_2^{FO}$ in as much as its petal edge is not tinged as it is in the latter case.

Yu and Chang (1948) further added six more alleles to the series, two of which were found in the indigenous material and four were synthesised from the existing types. The authors doubted the existence of such a single multiple allellic series and felt that the genetic substance affecting the characters in this so-called multiple allelic series for anthocyanin pigmentation of the Old World cottons is probably, in accordance with the genetic facts, separable into three sub-series which may really be three closely linked units situated at separable loci. On this basis there should be a multiple allelic series corresponding to each locus, viz., plant body colouration, ghost spot and spotless series. These consist of the following members: (*i*) plant body colouration series—full red, red margin, red margin (dilute plant body), red leaf, red vein, red calyx, sun red, thumb-nail red, green plant body; (*ii*) ghost spot series—tinged on ghost, ghost, basic recessive; and (*iii*) spotless series—tinged on spotless, spotless, basic recessive. Number of possible combinations among the series is sufficient to account for existing types. The authors also suggested a new system of nomenclature of anthocyanin characters which was self expressive.

The pseudoallelic anthocyanin series in the Old World cottons depend, according to Stephens (1948), on the interaction of at least three neighbouring loci, two of which (**G** and **S**) govern the presence or absence of a spot at the base of the petal and its pigmentation when present. When both of these genes are present, there is a red spot; when **G** alone is present the spot is white; when **G** is absent the petal is spotless. Stephen's studies on pigment

development in the petal favoured the hypothesis that **G** converts a yellow pigment to a leuco substance, and that **S** further converts the leuco substance to a red pigment. Chemical studies of the flower pigments have shown that flavonols provide a more or less uniform background colour in the petal upon which various anthocyan patterns are superimposed (Stephens, 1954). Stephens (1948) has reported that the leuco substance of the petal can be converted *in vitro* by reduction to an anthocyan pigment and the naturally occurring anthoxanthin (flavonol) can be reduced *in vitro* to an anthocyan pigment *via* an intermediate leuco substance. Genetic and chemical evidence combined, therefore, suggests that the leuco substance is an intermediate stage and a probable common precursor in the natural syntheses of both anthoxanthin and anthocyanin in the petal (Stephens, 1948). On the basis of this interpretation, Stephens (1948) indicated that the genes **G** and **S** are situated in neighbouring loci, they control similar reductional processes and act on very similar though not identical substrates (leuco substance and anthoxanthin).

Silow (1941) discovered yet another locus, $\mathbf{R}_3$ for anthocyanin development. He showed that red petal spot in *anomalum* is not due to a single gene, but due to complementary interaction between Ghost allele in $\mathbf{R}_2$ locus of the Old World cotton and a spotless allele in a duplicate anthocyanin locus. The spotless gene is characterised by a pleiotropic gold petal expression. It is assigned symbol $\mathbf{R}_3^{GO}$. *Gossypium arboreum* and *herbaceum* carry in the duplicate locus a basal recessive allele lacking both anthocyanin expression and spot characteristic. It is symbolised as $\mathbf{r}_3^{OO}$.

Paranjpe (1955) has reported the occurrence of plants showing blue-red pigmentation in young plant organs up to the flowering period in *arboreum*. One recessive determinant appeared to govern this character. It was designated **gt** since it was not found to be allelic with any of the three anthocyanin loci.

In the New World cottons considerable work has been done on petal spot and anthocyanin colouration. Detailed investigations have led to the conclusion that an extensive multiple allelemorph series for anthocyanin pigmentation exists in the New World cottons and that the factor for red plant body (**R**) in *barbadense* and *purpurascens** is actually a member of the multiple allele series at (**S**) for petal spot (Harland 1939).

The following table summarises the present information in regard to the genes governing anthocyanin pigmentation and their expression in the New World cottons.

There are thus at least five alleles in the New World series. The number may be more than this, since it is probable that the petal spot genes in *darwinii** and *taitense** are further alleles at the same locus.

So far as petal spot in the New World cottons is concerned Harland (1936a 1937, 1939) has summarised the position as follows.

Species	Plant body	Petal spot	Gene symbol
G. hirsutum	Red	Spotless	**R**^{A*}
	Green	Full	**S**^{H}
	,,	Absent	**s**
*G. purpurascens**	Red	Absent	**R**
	Green	Full	**S**^{P}
	,,	Absent	**s**
*G. taitense**	Green	Intermediate	**S**
G. barbadense	Red	Weak or Absent	**R**^{B}
	Green	Full	**S**^{B}
	,,	Weak or Absent	**s**
*G. darwinii**	Green	Full	**S**^{D}
G. tomentosum	Green	Absent	s

* Transferred to *hirsutum* from *arboreum* (From Harland, 1939).

1. Petal spot in the New World cottons is due to a series of basal spot, genes differing from species to species in: (*i*) relative potency on standard genetical background; and (*ii*) mutability.
2. Spot in *barbadense* is due to gene **S**^{B} which is accompanied by a series of plus modifiers. It also mutates to recessive allele and gives Pima spotless. The presence of colouration with varying intensity is due to modifiers. The **Y** gene (Yellow corolla) also acts as a strong modifier of **S**^{B}.
3. Spot in *hirsutum* is due to **S**^{H} (a relatively rare gene) which is an allele of **S**^{B} and of spotless **s**.
4. Spot in *purpurascens** is due to a third gene **S**^{P} which differs from **S**^{B} and **S**^{H}.
5. Although investigations are incomplete, it is likely that the spot in *darwinii** is due to yet another gene **S**^{D} on the same locus as **S**^{B}, **S**^{H} and **S**^{P}.

Red plant body in *hirsutum* has been found by various workers to be due to a single gene, fully dominant ever green. Harland (1939) confirmed that this red colouration gene in *hirsutum* gave monohybrid inheritance. He pointed out that a cross between *hirsutum* red and *barbadense* red gave all reds; these

reds when backcrossed to green gave 3:1 ratio indicating thereby that the *hirsutum* red, $\mathbf{R}_1^{RO}$ ($\mathbf{R}^H$) is not a member of the anthocyanin multiple allele series but is a duplicate gene.

A further type of anthocyanin pigmentation which causes reddening of leaf veins and stem in *darwinii** has been found to be partially dominant and due to a gene $\mathbf{R}^D$. It is not a member of multiple allelomorph series described since it shows dihybrid inheritance, with petal spot $\mathbf{R}_2$ (**S**) series. Its relationship with $\mathbf{R}^H$ has not so far been determined, but its weak expression on *hirsutum* background indicates that it is different from *hirsutum* gene.

Lewis and McFarland (1952) studied segregation of the $\mathbf{R}_2^{AF}$: $\mathbf{R}_2^{AO}$ (tinged stem+full petal spot: tinged stem, spotless) genes in three intra-*hirsutum* backcrosses. The $\mathbf{R}_2^{AF}$ gene showed varying expressivity in different backcrosses. In some it expressed itself so weakly that careful examination by a hand lens was necessary to detect few coloured cells in the petals. Deficiency of this gene in one of the backcrosses was considered to be a matter of reduced expressivity rather than an actual elimination of the gene.

LEAF CHARACTERS

Leaf Colouration. Patel, Munshi and Patel (1947) reported the occurrence of a mutant in *herbaceum* wherein all the leaves and the bolls of the plant were pale green. It was recessive to normal dark green, the F_2 giving normal and pale green in 3:1 ratio. No gene symbol has been proposed by the authors.

In the New World cottons, the green colour of the leaves of Uplands (*hirsutum*) is lighter than that in Egyptian (*barbadense*) cotton. Balls (1912) and Kearney (1923a) studying their inter-crosses, found that the leaf colours could not be satisfactorily graded and that the inheritance of this character was complex.

Leaf Lobing. Ramiah and Bholanath (1943) discovered a mutant having entire 'lanceolate' leaves, the usual lobing characteristic of cotton being practically absent or rudimentary. They found that this non-lobing was governed by a single recessive gene, normal lobing being fully dominant. The factor pair was assigned the gene symbols **S-s**. This gene was found to be independent and different from the usual leaf shape multiple allelic series to be discussed later.

In the New World cottons, a similar type, called Superokra is encountered, but it is a member of leaf shape allelic series.

Leaf Shape. Wide variation in the leaf shape of Indian cotton attracted the attention of the early workers. Fyson (1908), using eye classification, thought that the narrow and broad lobing of leaves of cotton in the cross of *neglectum** (narrow) and *herbaceum* (broad), behaved in a mendelian fashion narrow being dominant.

Leake (1911a, b) studied the inheritance of leaf shape using the quantitative shape expression 'leaf factor' calculated on the basis of measurements of: (*i*) length of leaf from petiole to the tip of middle lobes; (*ii*) distance from petiole to sinus between the middle lobe and the first lateral lobe ; and (*iii*) greatest width of the middle lobe. Although the variations in the magnitude of the leaf factor occurred from leaf to leaf on the same plant, Leake found that by choosing two typical leaves, he could get approximation to the leaf shape of the plant. The F_2 of two crosses (*arboreum* var. *nanking** x *arboreum*) between narrow and broad lobed types gave a curve corresponding to 1:2:1 ratio. In F_3 plants from parental classes bred true, while plants from intermediate groups segregated. A high correlation occurred between the means of parents and the means of offspring and it was evident that segregation also took place for minor factors affecting leaf shape. A cross between *arboreum* and *herbaceum* gave a monomodal curve which was not analysable.

Kottur (1923) studied the cross, *arboreum* var. *rosea** x *obtusifolium* var. *wightiana**. Considering that 'leaf factor' could not be regarded as a single unit character in inheritance studies because it was more variable than the elements of which it was made, he studied, instead, the measurement of length and breadth of the middle lobe. The F_1 possessed long and broad middle lobes ; the range of length exceeded that of the parent with long middle lobes. The F_2 curve for length was plurimodal and that for breadth unimodal.

Afzal (1930) reported that depth of laciniation in *cernuum-indicum* cross inherited simply.

Hutchinson (1934) presented a detailed analysis of the inheritance of leaf shape in the Old World cottons. He concluded that the leaf shape in these cottons was of five main types due to a series of multiple alleles, viz., L^B (mutant broad), L^I (mutant intermediate), L^L (laciniate), L (narrow) and l (broad). It was also found that L locus is mutable. In crosses of *arboreum* with *herbaceum*, the influence of minor genes affecting lobe shape, leaf size and degree of rumpling are of great importance and it is not possible, as it is in intra-*arboreum* crosses, to express almost the whole difference in leaf shape in terms of the main gene for laciniation. *H. herbaceum* and *arboreum*, both possess modifier groups affecting leaf shape and it is these which are of taxonomic significance.

Hutchinson, Ghose and Bholanath (1939) found a new allelomorph L^N, in a strain 1090 obtained from Nagpur (Bombay State). It has more deeply cut sinuses giving a higher value for 'Index A.' than types carrying L but showing about the same value for 'Index B'. They also felt that the leaf shape allelomorph series was not as simple as proposed originally by Hutchinson (1934). The new allelomorph failed to fit in the series since 'Indices A and B' did not run parallel. It was considered probable that sinus length and lobe width were controlled by independent portions of the gene.

Silow (1939a) also discovered $\mathbf{L^N}$ independently in *arboreum*. This and another factor $\mathbf{L^A}$ (discovered from *anomalum*) proved to be members of the leaf shape allelomorph series. He pointed out that these factors behaved as typical shape genes affecting relative growth in three directions. It appeared to the author that two primary components of leaf shape, laciniation and lobe width, were independently controlled. It was, therefore, postulated that the gene is a compound one, with two gene centres controlling laciniation and lobe width, respectively. The allelomorphs are serially arranged on the basis of difference in episome number on these two gene centres.

(*a*) With reference to laciniation: $\mathbf{L^L} - \left\{\begin{matrix}\mathbf{L^N} \\ \mathbf{L^A}\end{matrix}\right\} - \mathbf{L} - \mathbf{l}$

(*b*) With reference to lobe width: $\mathbf{L^L} - \left\{\begin{matrix}\mathbf{L^N} \\ \mathbf{L}\end{matrix}\right\} - \left\{\begin{matrix}\mathbf{L^A} \\ \mathbf{l}\end{matrix}\right\}$

Balasubrahmanyan (1951) reported the appearance of a narrow leaved mutant in a progeny of *arboreum* race *indicum* with X-ray. The narrow leaf was found to have incomplete dominance on its being crossed to the normal broad, F_2 gave narrows, intermediates and broads in 1:2:1 ratio.

In the New World cottons, leaf shape variation caused mainly by difference in degree of laciniation exists. Leaf shape is determined by a series of multiple alleles, the following members of which have been identified (Harland, 1939).

$\mathbf{l^o}$ ($\mathbf{O^N}$) *hirsutum* normal

$\mathbf{L^o}$ ($\mathbf{O^O}$) *hirsutum* Okra—recorded in several varieties of commercial Upland.

$\mathbf{L^S}$ ($\mathbf{O^S}$) *hirsutum* Super Okra—occurred in Acala Okra variety—laciniation extreme.

$\mathbf{O^P}$ *purpurascens** laciniated—called 'Cassava' because the leaves resemble those of Cassava plant, also found in another *purpurascens** type named Jamaica Xerophyte.

$\mathbf{O^D}$ *darwinni** laciniated

$\mathbf{O^B}$ *barbadense* normal.

The inheritance of leaf shape in the New World cottons is governed by multiple alleles as in the case of the Old World cottons. Mutability at **'O'** locus of *hirsutum* has also been reported. Horlacher and Killongh (1932a) have shown that $\mathbf{O^O}$ (Okra of *hirsutum*) can, under influence of X-ray, mutate to normal gene $\mathbf{O^N}$. A recessive mutation for round leaf has been reported by Lewis (1957; in *hirsutum*, this same gene causes the bract to be smaller and less toothed than a normal bract.

Leaf Nectaries. In the Old World cottons the leaves may or may not possess nectaries. Leake and Ram Prasad (1914) crossed *G. arboreum* having three

nectaries on the leaves of the main stem and monopodia with *G. nanking* var. *bani**, which has no such nectaries. In F_1, leaves on the main stem and some monopodia had three nectaries, others had one. In F_2, segregation took place in presence and absence of nectaries in the 3:1 ratio suggesting monohybrid inheritance.

Kottur (1923), however, in his studies on the cross of *herbaceum* (nectaries present) with *arboreum* (nectaries absent) found that the proportion of no-nectary class in F_2 was far in excess of the one anticipated on 3:1 ratio.

Hutchinson and Silow (1939) have suggested **Ne-ne** as gene symbols for presence and absence of nectaries.

FLOWER CHARACTERS

Corolla Colour. Corolla colour in the species of *Gossypium* studied is reported to be dependent upon the presence or absence of two distinct classes of sap-soluble pigments—anthocyanins and flavonols (Stephens, 1954). These two classes of pigments are controlled by independent genetic systems and with few exceptions there is little physical interaction between them. In most cases their effects can conveniently be considered as additive; the flavonols, providing a more or less uniform 'background colour' in the petals upon which the various anthocyan patterns are superimposed. The term 'corolla colour' should properly refer to the effects of both the flavonols and anthocyan pigments, but by common usage by cotton geneticists it had come to be restricted to the background colour only, i.e., to the effects of flavonol pigments *per se*. Genetics of anthocyanin colouration has already been dealt with; that of flavonol pigmentation in corolla is considered here.

Corolla colour varies in the Old World cottons from deep yellow to ivory white. The wild African species, *G. anomalum* and *G. stocksii* have both a creamy white corolla. Fletcher (1907) found yellow flower dominant over white. Fyson (1908) studied crosses between yellow and white-flowered types. He found that the F_1 was yellow and the F_2 segregated sometimes into yellow, pale yellow and white and sometimes into full yellow and whites only. In the latter case there was a monohybrid segregation.

Leake (1911a, b) and Leake and Ram Prasad (1914) reported that there are two allelomorphic pairs of factors involved in the crosses of full yellow with pale and white. The relationship between white and pale was not investigated.

Kottur (1923) crossed full yellow of *herbaceum* and white of *arboreum*. The F_1 was pale. F_2 consisted of pales, full yellows and whites in 39:9:16 ratio, which he explained as being a modified trihybrid ratio. He postulated the existence of these factors: (*i*) **A**, a basal factor for yellow, which converts white to pale and in the absence of which the flower is white; (*ii*) **B**, a factor which converts full yellow to pale, but by itself it is inoperative; and (*iii*) **C**,

which converts **A** to full yellow, but only in absence of **B.** The genotypes in the cross according to this scheme were:

Parents:			White (**aBc**) x Full Yellow (**AbC**)	
F_1:			Pale (**Aa Bb Cc**)	
F_2:	**27ABC**: Pale	**9aBC**: White	**9ABc**: Pale	**9AbC**: Full Yellow
	3abC: White	**3Abc**: Pale	**3aBc**: White	**1abc**: White

There were thus 39 pale, 9 full yellow and 16 white. The observed results were close to the expectation and were also confirmed by F_3 and F_4 data, though based on a small number of families.

Hutchinson (1931) confirmed Leake's work and explained Kottur's findings. He established that: (*i*) full yellow, Leake's pale and white constitute a multiple allelomorph series designated as (**Y**), ($\mathbf{Y}_p$); (*ii*) the correlation between petal colour and petal size holds good for minor factors affecting corolla colour as well as for three members of the multiple allelomorph series; and (*iii*) the occurrence of plants with short petals and yellow flowers, or long petals and white flowers is due to the reshuffling of modifying factors, there being a physiological relationship between petal colour and size.

Silow (1941) reported that a yellow-flowered *arboreum* strain found in China was similar to $\mathbf{Y}_p$ and yet distinguishable from it. Although greater part of the lamina of the petal is yellow (grade 2), there is a very slight intensification of yellow towards the base of the petal round the margin of the anthocyanin spot, a tendency absent from the more common type of pale. This 'pale' was complementary to the 'common pale' and 'white' flowered strains giving 'full yellow' in combination The demonstration of complementary factors necessitated the addition of subscript to the symbol used by Hutchinson and as such the Chinese pale factor was given the symbol, $\mathbf{Y}_b{}^P$ and the multiple allelomorph series described by Hutchinson was designated as $\mathbf{Y}_a$, $\mathbf{Y}_a{}^P$ and $\mathbf{Y}_a$. Unlike the mutants as $\mathbf{Y}_a$ locus the pale mutant at $\mathbf{Y}_b$ locus did not show any pleiotropic effect on petal size

Bholanath (1942), working with a Chinese cotton, found that the pale petal in the material was due to a complementary gene; probably the same ($\mathbf{Y}_b{}^P$) as that referred to by Silow (1941).

Silow (1941) further reported that pale flower colour in *anomalum* was complementary to common pale or white allele carried at $\mathbf{Y}_a$ locus or Chinese pale at $\mathbf{Y}_b$ locus. The gene responsible for pale corolla in *anomalum* has been assigned the symbol, $\mathbf{Y}_c{}^P$. *Anomalum* pale is modified towards 'pinkish' grade by the presence of anthocyanin in addition to the flavonol pigment (Stephens 1954).

The interactions of the triplicate loci, Y_a, Y_b and Y_c, on an *arboreum* background as summarised by Stephens (1954) are reproduced in Table 73.

TABLE 73. THE INTERACTIONS OF THE LOCI Y_a,Y_b AND Y_c ON AN *arboreum* BACKGROUND

Corolla colour type	Genotype	Phenotype	Species in which found
Yellow	Y_a Y_b Y_c	Yellow	*arboreum*, *herbaceum*
Common pale	Y_a^p Y_b Y_c	Uniformly pale	*arboreum*
Chinese pale	Y_a Y_b^p Y_c	Pale with intensification around 'throat' of corolla	Chinese strains of *arboreum*
anomalum pale	Y_a Y_b Yc^p	Uniformly pale	*anomalum*
White	y_a Y_b Y_c	White	*arboreum*
Pale combination	Y_a^p Y_b Y_c^p	Near white	Synthetic (Silow, 1941)
Pale	Y_a Y_b^p Y_c^p	White with intensification around 'throat' of corolla	A Chinese *arboreum* strain (Stephens, 1954); Synthetic (Silow, 1944)
Double recessive	y_c Y_b^p Y_c	White (indistinguishable from 'white' above)	Synthetic (Stephens, 1954)

Note: For convenience, the genotypes are listed in gametic terms and not zygotic terms.

Furthermore Silow's (1941) studies have shown that *anomalum* carries a yellow depressor (**Ydp**) gene which reduces the intensity of full yellows in *arboreum* (grades 7-8 to grade 4). The depressor, like other corolla colour modifiers, restricts petal length to a very slight extent.

Patel, Munshi and Patel (1947) described the occurrence of a pale petal plant (corresponding to grade 2 or 3 of Hutchinson) in *herbaceum*. It closely resembled the pale of Comilla (*arboreum* race *cernuum*). Its crosses with Comilla pale, probably Y_a^P, and Y_a gave full yellow F_1s; F_2s gave yellow, pale and white in 9:3:4 ratio, thereby suggesting complementary nature of *herbaceum* pale-Y_b^P. Its crosses with another white-flowered mutant in *herbaceum* (Wagad) reported by Patel and Mankad (1926), gave a full yellow F_1, and yellow, pale and extra white in 9:6:1 ratio in F_2 suggesting the complementary nature of the factors involved. It is not known whether Wagad pale is the same as Comilla pale carrying Y_a^P. Furthermore, the homology of Surti (*herbaceum*) pale with Chinese pale Y_a^P was also not tested.

In the New World cottons the inheritance of corolla colour has been studied by Balls, McLendon, Harland, Burd and Kearney (see Harland, 1939). Pale cream of Upland or Sea Island white and yellow in the series of types comprising seven grades of increasing pigmentation in *barbadens* or *purpurascense**, are governed by an allelomorphic pair of factors Y_1–Y_1 (Y^B–Y^B). This factor pair, (Y^B-Y^B) or other alleles with similar effect at the same locus, control corolla colour in the New World species, *barbadense*, *purpurascens** and *tomentosum*. In *darwinii** another factor for yellow corolla occurs; it is denoted as, Y_2 (Y^D). The pale type, y_1 y_2 is common in *hirsutum* and

infrequent in *barbadense* (Stephens, 1954). Superficially the genetic situation appears to be far simpler than in the Old World species studied.

Stephens (1954) has shown that glucosides of three flavonols, gossypetin, quercetin are present in *Gossypium* species. His chromatographic studies suggested that genetically different pale, off-white, cream or yellow flowers contain different flavonols. He suggested that probably white-flowered types like the *roseums* in *arboreum* are unable to synthesize appreciable amounts of flavonol pigment, that pale types are able to synthesize herbacetin and/or quercetin and that only the yellow-flowered types are able to synthesize gossypetin.

Petal Length and Shape. Leake (1911a, b) reported that there was absolute correlation between the size and colour of corolla and that there were no exceptions in F_2, the long petal being invariably yellow and white petal being short.

Kottur (1923) worked with a cross between *arboreum* and *herbaceum* involving long and short petal characters. He found that the petal length of F_1 was intermediate. F_2 showed a full range of segregation between long and short. Correlation was observed between petal length and corrolla colour.

Hutchinson (1931) agreed with Leake and found that the multiple allelomorph series for flower colour also governed the petal length, the terms of the series being full yellow (long petal), intermediate yellow (intermediate petal) and white (short petal). Minor factors for corrolla colour also affected petal length.

In the New World cottons, in the *hirsutum-barbadense* cross, Balls (1912) found that, long petal was dominant in F_1 and a complex segregation was obtained in F_2. *Barbadense* petal has a distinct lip at the base which is absent in most Uplands. The presence of lip is partially dominant in F_1, F_2 giving parental types and intermediates.

Sikka and Avtar Singh (1953a) have recorded the occurrence of a dominant mutant in *hirsutum* possessing a glistening appendage to each of the petals.

Meristic Variants. Ramanatha Ayyar (Ramanathan) and Balasubrahmanyan described the occurrence of 'meristic variants' in the irradiate progeny of *G. arboreum* race *indicum*. This character brought about increase in number of floral parts such as bracteoles, petals, and also boll loculi. This abnormality was found to be controlled by a single recessive gene, normal being fully dominant. This factor pair was designated **M-m** by Hutchinson and Silow (1939). It is now designated as $\mathbf{M_1}$-$\mathbf{m_1}$.

Govande (1946) reported the occurrence of a mutant characterised by indefinite number of whorls of bracteoles and petals in *herbaceum*. The mutant plant was monopodial in habit and its flowers did not open freely. The mutant when crossed with normal plant gave F_1 plants which had normal flowers. The F_2 gave normals and mutants in 3:1 ratio, showing thereby the monogenic

inheritance of the character. The gene pair for this character has been designated as M_2-m_2 (M^B-m^b): normal—multi-bracteolate flowers.

Petalody. Ramanathan and Sankaran (1934) reported the occurrence of partial or complete petalody in the androecium whorl of *arboreum* race *indicum*. The petalodic character is a simple recessive to normal. Hutchinson and Silow (1939) have designated normal and petalodic by gene symbols **Pdy-pdy**.

Hutchinson and Ghose (1937d) pointed out that dominance of normal condition over petalody was incomplete and that F_2 gives 1:2:1 segregation.

A new type of petalody termed 'pistillate' was reported in *arboreum* by Iyer (1947). The androecium was represented by petaloid staminodes or green ovule bearing appendages. On crossing to normal, cylindrical fluted bolls were obtained. Balasubrahmanyan and Santhanam (1951b) reported that the character is governed by a single recessive gene **pte**.

Afzal and Singh (1939) reported that 'double flowered' fertile *arboreum* shows a simple factor difference with the normal, hetorozygote being intermediate. Expression of the 'double flower' gene weakened as the plants aged.

Pollen Colour. Pollen colour varies from deep orange to practically white in the genus *Gossypium*; genetics of the character has been studied in six species only. According to Stephens (1954), pollen colour is best judged by examining anthers one or two days before the flowers open.

In the cultivated Old World species pollen is deep yellow in colour in most cases. Cream and pale yellow coloured pollen has been reported in some cases. Ramanathan and Balasubrahmanyan (1933a) reported a plant with cream pollen in Cocanada cotton, *arboreum* race *indicum*. This 'cream' latter styled as 'pale' by Silow (1941), was found to be a simple recessive to normal. Silow (1941) reported the occurrence of a plant with cream coloured pollen in a strain of Russian *herbaceum*. The cross between *herbaceum* cream and *arboreum* pale pollen, gave F_1 with full yellow pollen thereby showing the complementary nature of the pale and cream. The gene symbols P_a and P_b have been assigned to *herbaceum* cream and *arboreum* pale pollen, respectively. Genotype of *anomalum* is reported to be P_a P_b; pollen colour being cream (Silow, 1941).

In the species of **Hirsuta** inheritance of pollen colour was studied by Balls, McLendon, Kearney and Harland. Harland (1939) and Stephens (1954) summarised the whole position and pointed out that a single genetic difference is involved in all crosses between any grade of yellow and cream (**P-p**). Modifying genes act on basal gene for yellow, producing a complex series of shades from pale yellow to orange (deep golden). These modifying genes could be carried by cream, producing in it minute variations in shade. Later work showed that the gene for yellow pollen (**P**), of alleles with closely similar effects, occur also in *darwinii*,* *purpurascens** and *tomentosum*. Thus **P**

is common in *barbadense*, more rare in *hirsutum* and the only type in *tomentosum* whereas **p** is common in *hirsutum* and rare in *barbadense*.

Calyx Ring — Outgrowths. Jagannatha Rao (1933) noted small outgrowths on calyx ring of cotton flower in a variety of *arboreum* race *indicum*. In F_1 of the normal x abnormal, the character was partially dominant.

Bract Size. In *hirsutum*, Stephens (1947a) recorded a mutant type with a greatly reduced bracteole which withered before the balls opened. Knight (1951) reported on its inheritance in intraspecific hybrids. The character was governed by one main recessive gene, **bw** subject to considerable modification by minor genes. It is markedly deleterious by itself and when modified by minor genes it is only slightly deleterious and at the same time does not cause the bracts to wither away effectively. It was, therefore, inferred that the gene was of no value to plant breeders. Again in *hirsutum* a simple recessive mutation showing a narrow bract has been recorded by Lewis (1957). It is called frego bract mutant. A loss of dominance of the non-frego bract gene on a genetic background homozygous for round leaf has been noted since such a plant produces frego bracts even when heterozygous for the frego genotype.

BOLL CHARACTERS

Boll Shape and Size. The Old World cottons show a large variation both in shape and size of the bolls and a large number of forms breeding true for a particular shape and size are found.

Patel and Patel (1927) observed the behaviour of 'greatest boll diameter' and boll shape in crosses of two variaties of *herbaceum*, 1027A L.F. or 1A Long Boll with Goghari E.5. They found that while F_1 was intermediate, F_2 presented a unimodal curve showing thereby the polygenic control of these characters.

Afzal (1930) studied the inheritance of the length and breadth of bolls in a cross between *G. cernuum** and *G. indicum**. He found that the F_1 was intermediate and the F_2 segregates showed monomodal distribution indicating hereby that these characters were controlled by multiple genes.

Ramiah and Bholanath (1947) studied the inheritance of boll size in a cross between two varieties, Malvi 9 and Bishnoor, both belonging to *arboreum*. The former variety had a medium sized boll while the latter had a narrow leaf and large long bolls. The mean length and diameter of bolls of F_1 were almost like those of Bishnoor parent indicating dominance of large boll. The F_2 mean values compared to those of the parents grown in the same season were intermediate between both parents in boll diameter. Evidently boll size is controlled by multiple genes.

In the New World cottons, Balls, Kearney and Kokuev attempted the study of inheritance of the size and shape of boll in interspecific crosses involving *hirsutum* and *barbadense* and also in intra-*hirsutum* crosses (see Harland

1939; Stith, 1956). In all cases the F_1 was more or less intermediate and the F_2 showed unimodal curve indicating existence of multiple genes.

Boll Loculi. The number of boll loculi in both the New and Old World cottons range from two to five. In *arboreum* the commonest condition is three locked although some bolls may be four locked. Ramiah and Bholanath (1947) recorded a plant in *arboreum* which had 4-5 locked bolls and it bred true to this character. On crossing with normal three locked lines, F_1 showed complete dominance of normal three locked condition, F_2 showing segregation of normal and 4-5 locked condition in 3:1 ratio, indicating thereby the simple recessive nature of 4-5 lock condition.

Patel, Munshi and Patel (1947) reported a 4-5 locked variety bred from a mutant observed in 1027A L. F. (*herbaceum*). Its crosses with normal 3-4 locked condition showed that the latter was fully dominant. The F_2 showed 3-4 locked normal and 4-5 locked plants in 3:1 ratio. They also found that the recessive gene responsible for 4-5 locked condition was different from the one that brought about 4-5 locked condition in a Russian *herbaceum* type. Cross of indigenous 4-5 locked plant with Russian 4-5 locked *herbaceum* gave normal 3-4 locked plants in F_1 and F_2 segregated into 3-4 locked and 4-5 locked plants in 9:7 ratio. In the 'Whorled' mutant of *herbaceum* 2-3 locks have been reported (Chavda and Patel, 1954). The 2-3 lock and 4-5 lock conditions in *herbaceum* have been reported to be governed by a pair of complementary pseudo alleles, **loc.** $^{2\text{-}3}$ and **loc.** $^{4\text{-}5}$ (Bhat and Desai, 1956).

In the New World cottons crosses between parents differing in number of loculi in the bolls have been studied by Balls, McLendon, Harland and Kearney. In practically every case F_1 was intermediate more towards the value of low parent in some of the crosses. The F_2 gave skew curves and transgressive segregation (see Harland 1939). The evidence indicated that several factors were involved.

Type of Opening of Bolls. In both the New and the Old World cottons differences exist in the manner of opening of bolls. In some of the *herbaceum* types like Wagad, bolls scarcely open while in some *arboreums* they flare back to an extent of dropping the lint. The bolls of *hirsutum* types open more widely than those of *barbadense*.

Abraham (1934) states that certain members of the *arboreum* cottons, e.g., Karunganni, show incomplete dehiscence of the boll. The degree of opening was apparently dependent upon the extent to which ventral bundles of the carpels were fused in the placenta. The results of the crosses showed the fully opening condition to be dominant; segregation in F_2 comprised three fully opening: one incompletely opening classes.

Balasubrahmanyan, Santhanam and Mayandi Pillai (1949) reported another type of incomplete boll dehiscence observed in Cocanada (*arboreum* race *indicum*) cotton, in which the bolls are cup-shaped with carpellary clevage extending up to half boll length from tip. This was due to in-

complete formation of the line of dehiscence on the carpellary wall, stopping at one-third of the length of the boll from the tip. This type of boll dehiscence (Cocanada indehiscence) was found to be controlled by a single recessive gene **de_2** (**de_b**), normal opening being fully dominant in F_1. Another type of incomplete boll opening was noted in Wagad (*herbaceum*) cotton, where the carpellary line of dehiscence extended to the very base of the boll but the valves did not open out fully nor did they exhibit recurving as in normal bolls. This Wagad type of boll opening was also found to be controlled by a single recessive gene **de_1** (**de_a**), the normal being fully dominant. The two indehiscent boll types in the **Herbacea** species when inter-crossed gave normal F_1s, and F_2 gave a 9:3:4 segregation of normals, Cocanada indehiscent and Wagad indehiscent types. Complementary nature of **De_1** and **De_2** and epistasy of **de_1** over **de_2** was thus indicated.

Boll Surface. In the *barbadense*, boll is usually dark green and shiny, the *hirsutum* boll being paler green and dull. F_1 is intermediate and parental types with a series of intermediates occur in F_2. No fracterial analysis is possible (Harland, 1939). Kulkarni and Khadilkar (1929), however, had reported that F_1 between *hirsutum* (light green) x *barbadense* (Sea Island) (deep green) gave an intermediate F_1 and 1:2:1 ratio in F_2. It is probable that several factors are involved and that the apparent simplicity of these results is misleading (Harland, 1939).

LINT CHARACTERS

Lintlessness. Although presence of normal lint is the chief characteristic of the cultivated cotton plant, a number of lintless mutants have been recorded in the Old World and the New World cottons.

Afzal and Singh (1932) grew a lintless mutant of Mollisoni (*arboreum*) for four generations. The plant body was glabrous and the stigma protruded through the flower buds. In the F_2 of Mollisoni lintless x ordinary Mollisoni this floral abnormality was completely linked with the lintless condition.

Afzal and Hutchinson (1933) studied the genetics of two glabrous lintless types and one hairy lintless mutant in *arboreum*. They concluded that the glabrous lintlessness in both the types was governed by a recessive gene **h_a** (**h^G**) giving a glabrous plant with only a few short hairs on the seed. **H^G** gives a normal plant. The hairy lintless type was said to be due to another gene, **lic** (**h^1**), believed to be lethal in homozygous condition.

Hutchinson and Gadkari (1937) studying the genetics of four more lintless types: (*i*) glabrous lintless mutant in *arboreum ex* Nagpur; (*ii*) the Punjab glabrous lintless, a mutant in *arboreum* observed in the Punjab; (*iii*) hairy lintless fuzzy, a mutant in 1027A L. F. (*herbaceum*) observed at Surat; and (*iv*) hairy lintless naked, a mutant in Wagad cotton belonging to *herbaceum*. They found that glabrous lintless nature was due to either of the two simple

recessive genes, h_a and h_b. These two genes were complementary to one another for production of normal hairy linted nature. Hairy lintless nature as seen in *herbaceum* was again due to either of the two simple recessive genes li_a or li_b which were also complementary for lint production. A cross between these two hairy lintless types in *herbaceum* gave a normal hairy linted F_1 and normal and lintless segregated in 9:7 ratio in F_2. Crosses of hairy lintless, li_a or li_b with the glabrous lintless h_a or h_b gave a normal hairy linted F_1, F_2 segregating into hairy linted, hairy lintless and glabrous lintless in 9:3:4 ratio. Epistasy of genes on **li** over the genes on **h** locus is thus suggested. The Punjab Hairy Lintless gene, reported as homozygous lethal by Afzal and Hutchinson (1933), was found to be viable at Indore. The homozygous lintless was dwarf and possessed downy seeds. Its survival was considered to be the effect of mild favourable environment obtained at Indore as compared to that obtained in the Punjab. The relationship of the li_c gene with li_a and li_b has not been fully worked out.

Ramiah and Kaiwar (1942) studied the pleiotropic effects of the li_c gene and showed that it brought about reduction of general growth rate at the time of flowering which resulted in reduction of plant height and of the number and length of internodes. It also inhibited fibre development and adversely affected boll size and fertility. Gadkari and Ramiah (1951) showed that the apparent association of broad leaf with lintless gene, li_c, was not due to linkage but to the effect of the gene on growth, which resulted in the incomplete laciniation of the leaf, so that the leaves, which were genotypically narrow, appeared phenotypically broad.

Govande (1944b, 1948) described another hairy lintless mutant in *herbaceum*, called Baroda Lintless, which carried yet another complementary gene li_d. It gave a hairy linted F_1 with all lintless types except li_c and gave F_2 segregation in 9:3:4 ratio in case of crosses with glabrous lintless and in 9:7 ratio in its crosses with hairy lintless.

Gadkari (1950) reported the presence of another hairy lintless gene li_e responsible for lintlessness in Nandyal lintless, a mutant observed in N.14 (*arboreum* race *indicum*). This gene, like li_d, was again complementary to the genes li_a and li_b. Yet another lintless mutant has been recorded in *arboreum* (Gaorani 12-F_2) by Gadkari and Kocharekar (1951).

Balasubrahmanyan and Santhanam (1950b, 1952) have further reported two more hairy lintless mutants in Cocanadas (*arboreum* race *indicum*) cotton. Each one of them is controlled by a single recessive gene, normal linted being dominant. They have designated them as short lint, li_{sh} and sparse lint, li_{sp}. They did not test their homologies with other lintless genes.

Bholanath (Unpublished) working at Indore found that li_{sp}, and probably li_{sh} also, are identical with li_d. He has also recorded the presence of yet another complementary hairy lintless gene, li_f in a lintless mutant in Banila (*arboreum*).

Silow (1939b) showed that the members of the gene complex controlling lint quantity behave as modifiers of lintlessness. He classed these modifiers into epistatic and hypostatic series of lint quantity genes in relation to $\mathbf{h}_a$; the former series was present in *arboreum* races *indicum* and *sinense* and *herbaceum* var. *acerifolium**, the latter in *arboreum* races *bengalense*, *burmanicum* and *cernuum*. Gadkari (1950) has reported that a similar modifier action was effective in a series of experiments in which disturbed segregations involving the hairy lintless genes, $\mathbf{li}_a$, $\mathbf{li}_b$, $\mathbf{li}_d$ and $\mathbf{li}_e$, were obtained.

In the New World cottons, Griffee and Ligon (1929) reported that lintless *hirsutum* differs from fuzzy linted *hirsutum* in respect of a single factor, the former character being dominant.

Lint Colour. Lint colour in cotton may be white, creamy white, dirty grey, black, various shades of brown up to almost a mahogany red, khaki or a bright green which speedily fades to a greenish rust brown.

In the Old World cottons, Fletcher (1907) remarked that coloured lint is dominant over white. Kottur (1923) crossed a reddish tinged dull white *herbaceum* with a white linted *arboreum*. The F_1 possessed reddish tinged dull white lint and F_2 segregated into three whites or dull white to one brown. Silow (1944b) later explained these results as being due to the action of a single main gene obscured by the action of modifiers.

Ramanathan and Balasubrahmanyan (1933b) considered that lint colour in the Old World cotton is governed by three factors. They suggested that one basic gene, **X**, essential for colour, can produce pigmentation of the lint only in the presence of $\mathbf{K}_1$ and/or $\mathbf{K}_2$. None of them can impart colour individually. When either $\mathbf{K}_1$ or $\mathbf{K}_2$ was present with **X**, the lint was cream coloured. Both $\mathbf{K}_1$ and $\mathbf{K}_2$ are of equal potency in colour production. The three genes together produce brown lint. Several modifiers seemed to be present.

Hutchinson (1934) first reported that lint colour in the Old World cottons is controlled by a single khaki gene, **K**, linked with leaf shape locus, **L**. Later, however, he (1935) encountered lint colour segregation in backcrosses and, therefore, postulated the existence of three factors controlling the character. Of these, **K** was linked with leaf shape ; the others were symbolised, $\mathbf{d}_1$ and $\mathbf{d}_2$.

Silow (1944b) pointed out that lint colour in the Old World cotton species, *arboreum* and *herbaceum*, is determined by main genes at three loci $\mathbf{lc}_1$, $\mathbf{lc}_2$ and $\mathbf{lc}_3$ and by a variable complex of minor genes. Subsequently (1945), he reported the existence of still another locus $\mathbf{Lc}_4$. At $\mathbf{Lc}_1$ only one brown gene $\mathbf{Lc}_1^K$ ($\mathbf{K}_1$ or **K** of earlier workers) existed. It is nearly fully dominant. In interspecific crosses, it is not subject to modifier displacement and is only slightly subject to fading. Occasional mutation of this gene to white has been observed. At $\mathbf{Lc}_2$ a multiple allelemorph series occurs, khaki, medium brown, light brown, very light brown and white brown,—$\mathbf{Lc}_2^K$, $\mathbf{Lc}_2^M$, $\mathbf{Lc}_2^B$, $\mathbf{Lc}_2^V$ and $\mathbf{Lc}_2$. $\mathbf{Lc}_2^K$ ($\mathbf{K}_2$ of earlier workers) is regarded as duplicate of $\mathbf{Lc}_1$.

It possesses a slightly lower degree of dominance. $\mathbf{Lc_2^B}$ (D_1 of Hutchinson, 1935) is of low dominance and highly susceptible to modifier displacement and to fading. At $\mathbf{Lc_3}$ only one brown gene $\mathbf{Lc_3^B}$, (D_2 of Hutchinson, 1935), which is indistinguishable duplicate of $\mathbf{Lc_2^B}$, has been identified. At $\mathbf{Lc_4}$ only one khaki linted gene, $\mathbf{Lc_4^K}$ is known. Brown genes are cumulative in effect, when $\mathbf{Lc_2^B}$ and $\mathbf{Lc_3^B}$ occur together in homozygous phase their expression is darker than that of khaki allele. Homozygous $\mathbf{Lc_2^B}$ also raises homozygous $\mathbf{Lc_2^K}$ to the same intensity, but a light brown does not make any discernible difference to the expression of khaki when both are heterozygous. A single light brown gene at each of the $\mathbf{Lc_2}$ and $\mathbf{Lc_3}$ loci has the same phenotype as either of light browns in the homozygous phase.

As a result of high dominance of khakis, and their stability on exposure, both F_2 and backcross progenies segregating for them show comparative uniformity in the coloured class. Where the light browns are concerned, their susceptibility to fading leads to a considerable variability in the coloured class in a backcross, and their low dominance accentuates this in a selfed progeny. Nevertheless within *arboreum*, browns are usually quite distinct from whites, seldom fading below grade 05, but where modifier segregation occurs, as in most interspecific crosses, there is complete intergrading between brown and white. Lint colour intersifiers have no colour expression of their own in absence of the main colour gene.

Balasubrahmanyan, Mudaliar and Santhanam (1950) showed that different strains of Cocanada (*arboreum*) carry $\mathbf{Lc_2^B}$ and $\mathbf{Lc_2^V}$. Further, due to environmental effect and exposure, considerable colour variability was noticed in $\mathbf{Lc_2^V}$.

In the New World cottons, the lint colour situation has been summarised by Harland (1935b). It is pointed out that brown lint in New World cottons is conditioned by duplicate genes:

$\mathbf{K^B}$–$\mathbf{K^B}$ Brown-Light brown: *barbadense*

$\mathbf{K^H}$–$\mathbf{K^H}$ Brown-White: *hirsutum, taitense**.

Hutchinson and Silow (1939) designated the symbols $\mathbf{K^B}$ and $\mathbf{K^H}$ as $\mathbf{Lc_1^K}$ and $\mathbf{Lc_2^K}$, respectively.

Silow (1944b), reviewing the literature pertaining to inheritance of lint colour in the New World cottons, suggests that lint colour situation in them has a close parallel to the one in the Old World species. Main lint colour genes are uncommon in *hirsutum* except near the centre of diversity but the species as a whole is at a high level of modifying complexes. In *barbadense* on the other hand the modern slight creamy Egyptians and Sea Islands particularly possess one main brown gene and a strongly suppressing modifier background.

Gossypium hirsutum includes forms with bright green lint fading, on exposure to light, to brownish green. It is simple dominant to white, the

factor pair responsible being, **Lg–lg** as designated by Hutchinson and Silow (1939).

Hutchinson (1946c) demonstrated that genes determining brown lint in *G. punctatum** and *G. darwinii** are independent of **Lc$_1$^{K}**. Mohogany is distinct from all these in intensity of colour induced, and in being highly dominant. It also has large effects on lint length, maturity and fineness. Two brown genes are reported in *tomentosum* but their homologies have not been established. In Upland, a gene that intensifies brown but has no effect on white has been reported to occur. In *hirsutum* races *punctatum* and *marie-galante* and in *barbadense* and *tomentosum*, minor lint colour genes that change white to off-white, or even pale brown, or intensify brown, are reported to occur.

Brain (1950) studied genetics of brown lint character in five *hirsutum* types and one *barbadense* type. Four of the *hirsutum* types carried members of the same series of alleles for lint colour ; the remaining two types carried two independent loci for the character.

Lint Immaturity. Balasubrahmanyan, Mudaliar and Jagannatha Rao (1947) described a mutant in Cocanadas cotton (*arboreum* race *indicum*) whose lint was immature in spite of the seed being normal. This character was found to be controlled by a single recessive gene, normal being fully dominant in F_1 and F_2 showing normal and immature lint in 3:1 ratio. The authors assigned the gene symbols **Lm—lm** to this factor pair. Apart from this major gene, the possible role of minor genes controlling fibre maturity in Cocanadas has been indicated by Kalyanaraman, Santhanam and Ramchandran (1956).

Lint Index. Lint index is defined as weight of lint in grammes on 100 seeds of cotton. It would be appreciated that this is a compound character being a function of: (*i*) mean number of hair per seed ; and (*ii*) mean hair weight. As such it would be difficult to carry out its genetic analysis on simple mendelian lines. Breeders have succeeded in developing lines which would breed true to a large number of different mean values of lint index separated by imperceptible steps (Harland, 1939).

In a cross between two varieties of *herbaceum*, Patel and Patel (1927) found that F_1 was intermediate between the parents with respect to lint index and F_2 showed monomodal curve. This indicated that the character is controlled by multiple genes.

In Cocanadas (*arboreum*) two mutants having low lint index have been reported, one having short but mature lint and the other having immature lint of normal length. Their F_1 hybrid showed high lint index and F_2 segregated in the ratio of 9:7 for plants of high and low lint indices, respectively. Kalyanaraman, Santhanam and Ramchandran (1956), therefore, inferred that the F_1 was heterozygous for two genes, short lint (**li$_{sh}$**) and immature lint (**lm**).

Quantity of lint on seed in Upland cottons is reported to be governed by two genetic systems. A single pair of factors having pleiotropic effects on both fuzziness and production of lint was reported by Griffee and Ligon (1929). Another genetic system is composed of a complex of modifiers, which independently have minor effects of lint production but which may have a considerable effect as a group. For increasing lint quantity such modifiers need to be isolated, identified and tested in various combinations, and then transferred to commercial cotton varieties (Richmond, 1949).

Ginning Percentage. Ginning percentage, often called as the lint percentage or ginning outturn, is defined as $\dfrac{\text{Lint index x 100}}{\text{Lint index + Seed weight}}$

In commercial sense, it is the weight of lint in lb. obtained from 100 lb. of seed cotton. It is evident that this is a complex character depending on various factors.

Kottur (1923) working with a *herbaceum-arboreum* cross, indicated monofactor segregation, high ginning being dominant. His conclusion, according to Harland (1939), did not appear to be well founded.

Patel and Patel (1927) found that within *herbaceum*, crosses between high and low ginning types gave F_1s with intermediate values of ginning percentage, and F_2 showed a unimodal curve thereby indicating the multiple gene control of the character.

In the New World cottons McLendon (1912), O'Kelly and Hull (1930), Ware (1929a), Kokuev (1935) and Stith (1956) studied the inheritance of lint percentage. All their results indicate the multiple gene control of the character.

Lint Density Index. Thurman and Henderson (1956) have studied the inheritance of this character in Upland varieties. There was absence of dominance in F_1 and F_2 and the character proved to be quantitative in inheritance. Relatively large parent differences appeared to be governed by not more than five or six pairs of genes.

Lint Length. The length of unicellular spinnable hairs springing from the seed coat, collectively known as lint and constituting the main commercial product of the cotton plant, varies from less than one-eighth of an inch in wild types to more than two inches and a quarter in superfine Sea Island cotton.

Fletcher (1907) states that in the Old World cottons long lint is dominant over short. Kottur (1923) also showed that in a *herbaceum-arboreum* cross long lint is dominant over short lint.

Patel and Patel (1927), studying a cross between two varieties of *herbaceum*, found that staple length of F_1 hybrids was intermediate. The F_2 segregates gave monomodal distribution for the frequencies of staple length, suggesting thereby that the character is controlled by multiple genes. A short lint mutant in Cocanadas (*arboreum* race *indicum*) has been reported to be monogenic

recessive by Kalyanaraman, Santhanam and Ramchandran (1956). Balasubrahmanyan and Santhanam (1952) assigned the symbol $\mathbf{li}_{sh}$ to this gene and found it to be epistatic to $\mathbf{li}_c$ in crosses with Nandyal (*arboreum*) hairy lintless giving in F_2, normal, short linted and lintless plants in the ratio of 9:3:4.

In the New World cottons various workers found that in crosses between long and short staple varieties the F_1 was either intermediate in staple or long lint was completely dominant. In most cases, F_2 showed unimodal distribution suggesting polygenic nature of the character (see Harland, 1939; Ware, Jenkins and Harrell, 1943; Stith, 1956). In the American Uplands, according to Murray (1947), four or possibly five genes seem to be involved in lint length, of which two or three may have major effects. In the material studied by Murray, the major factors for lint length were approximately equal in their effect. However, the tendency towards negative skewness suggested that some of the genes for lint length may have interacted in a cumulative manner. Similar hybrid was studied by Vetez Fortuno (1956). The minimum number of genes governing staple length was estimated by Castle-Wright formula; it was 9·38. The heritability of staple length was 85 per cent. in F_2.

Lint Strength. Ware and Harrell (1944) studied inheritance of fibre strength in Upland crosses, the quality character showed intermediacy in inheritance. The manner of inheritance was inferred to be quantitative. Stith (1956) arrived at similar conclusion from his studies in the inter-racial hybrid of *hirsutum* Acala (race *latifolium*) with Hopi (race *punctatum*).

Lint Fineness. Fibre fineness is a hereditary character which varies under different locational and seasonal conditions. Ware (see Christidis and Harrison, 1955) reported that coarse lint is dominant over fine. Stith (1956) has reported that the character is quantitatively inherited.

SEED CHARACTERS

Fuzziness. In the cultivated Old World cottons the hairs on the seed are differentiated into distinct coats, one consisting of long fairly easily detached lint hairs, and the other of short strongly adherent fuzz hairs. In a few so-called 'tufted' types the latter coat is represented only by a few hairs at the chalazal end of the seed. Hutchinson (1935) found tufted to be due to a partially dominant gene **Fz** (**T**), whose expression was considerably influenced by modifiers. He made use of a series of grades for classification of segregating progeny in which grade 1 was the most highly tufted type (naked) and grade 6 almost fully covered except for small naked areas. Fully covered segregates were classified as 'fuzzy'. Homozygous tufted types fell under the grades 1-4 and the heterozygotes usually came under the grades 3-6.

In the New World cottons, the types of fuzz distribution met with are: (*i*) naked—characterised by complete absence of fuzz hairs; (*ii*) tufted—

characterised by a tuft of fuzz at the apical end of the seed; and (*iii*) fuzzy. Balls (1912), McLendon (1912), Kearney (1923a), Carver (1929) and others (see Harland, 1939; Richmond, 1949) worked on the inheritance of this character. On the whole, four factor pairs appear to have been established with certainty in the New World group:

F^n-f^n (**N-n**)—Naked—Fuzzy (*hirsutum*)

Ft-ft (**T-t**)—Tufted—Naked (*barbadense* and *purpurascens**)

Fm-fm (**S^m-s^m**)—Less fuzzy—More fuzzy (*barbadense*)

Fz-fz (**F^t-f^t**)—Tufted—Fuzzy (*hirsutum*)

Harland (1939) has remarked that there is probably a multiple allelomorphic series and also duplication of genes. In Indian varieties of *hirsutum*, the expression of the gene for *fuzziness* is subject to considerable variability by the modifier genes present (see Christidis and Harrison, 1955). In crosses between varieties having different modifier background the segregation of fuzz becomes complicated and even a reversal of dominance may be observed.

In the New World cottons, cross of a type with dominant naked seeded character with another with recessive naked seeds gave F_2 segregation suggesting dominant naked condition to be governed by an inhibitor factor and the other naked condition controlled by another single recessive allele (Ware, Benedict and Rolfe, 1947).

Seed Fuzz Colour. The fuzz on seed coat may be colourless or various shades of green or brown. The colouring matter is unstable and green fades quickly to brown, though some strains seem to retain their colour more firmly than the others.

In the New World cottons, the crosses of coloured (green or brown) fuzz types with white gave a coloured F_1 and F_2 segregated in coloured and white fuzz types (Cook, 1913). In many instances green appeared in crosses between apparently homozygous whites (McLendon, 1912). Harland (1939) found that green fuzz was always associated with green lint. In inter-Upland crosses, Carver (1929) reported the occurrence of two genes, brown **Fbr** (**B^r**) and green **Fgr** (**G**), the latter being epistatic to the former.

Seed Weight. The mean seed weight in cotton varies from less than 40 mg. to 200 mg. in different varieties. Each pure line has its own particular mean seed weight to which it breeds true. It is a character subject to great fluctuation and is influenced greatly by such characters as boll size, and number of seeds per locules.

Efforts have been made by workers in the past to study the crosses of high seed weight varieties with low seed weight ones, the F_2 segregation indicated a multifactor inheritance (see Harland, 1939).

RESISTANCE TO PESTS

In India, the New World cottons suffer most due to the ravages of pests; the major pests of cotton in the country being jassids and pink and spotted

bollworms. Efforts have so far been made only to study the inheritance of jassid resistance.

Jassid Resistance. Afzal (1941b) crossed 920 Cambodia, a resistant type with 58F, a susceptible type, both belonging to *hirsutum*. The F_1 appeared to be resistant. The F_2 grown in the year of heavy jassid attack consisted of a population of 43 resistant and 17 susceptible types, suggesting monofactorial type of segregation. Afzal and Ghani (1941) reported a high genetic linkage between hairiness and jassid resistance in hybrid progenies though a few cross-over plants were found.

Sikka and Avtar Singh (1953b) studied the inheritance of jassid resistance in seven crosses made between the Punjab *hirsutums* possessing varying degrees of jassid resistance. The crosses, grade 3 (slightly resistant) x grade 2 (medium resistant) and grade 1 (highly resistant) x grade 4 (susceptible), gave bifactorial segregation while the crosses grade 3 x grade 4 and grade 1 x grade 2 showed only monofactorial segregation. On the basis of these results it has been concluded that the jassid resistance in these cottons is controlled by two factor pairs.

Knight (1952) pointed out the fact, proved by other workers, that hairs of sufficient length and density on the underside of cotton leaves confer immunity to jassids. The resistance of two perennial *barbadense* types was shown to be due to a basic partially dominant hairiness gene designated $\mathbf{H}_1$ accompanied by a number of minor hairiness genes. The $\mathbf{H}_1$ was reported to be identical with gene $\mathbf{H}^B$ and $\mathbf{H}^{TA}$ of Harland (1944). In certain *hirsutum* types also jassid resistance is controlled by $\mathbf{H}_1$ accompanied by intensifying genes which augment its effect. Knight (1952, 1954b, d, 1955) has given proof that $\mathbf{H}_1$ is the major gene for hairiness controlling jassid resistance in *barbadense*, *hirsutum* races *latifolium*, *punctatum* and *marie-galante*, *herbaceum* and *arboreum*. Knight and Sadd (1954) have shown that, in all, three types of genes are concerned in the genetic control of hairs, of length and density sufficient to give jassid resistance, on the abaxial leaf surface:

1. Major and minor genes, the direct effect of which is to produce hairs. These have been referred to as **H** genes.
2. Modifying or intensifying genes which increase the length of hairs produced by **H** genes. These lengthening genes act on any hairs present regardless of their density or sparseness.
3. Modifying genes which affect the density of the hairs produced by **H** genes.

Another hairiness gene, $\mathbf{H}_2$, identical with Harland's (1944) $\mathbf{H}^{TO}$ is responsible for the dense *tomentum* of *G. tomentosum*.

RESISTANCE TO DISEASES

Hitherto efforts seem to have been made to study the genetics of resistance to two diseases only, viz., wilt and blackarm.

Resistance to Blackarm. Knight and Clouston (1939) showed that resistance to blackarm disease in American Upland cotton (*hirsutum*) is due to the presence of two dominant cumulative factors $\mathbf{B_1}$ and $\mathbf{B_2}$, together with minor genes constituting the modifier complex. Knight (1944b, 1953a) reported the presence of additional genes for blackarm resistance in *hirsutum;* they are $\mathbf{B_3}$ and $\mathbf{B_7}$. Knight (1953a) located $\mathbf{B_7}$ in the variety Stoneville 20 in which Blank (1949) had earlier reported that blackarm resistance was monogenic recessive to susceptibility. The $\mathbf{B_3}$ was reported to be linked with $\mathbf{B_2}$, cross-over value being 32·4 per cent. In *arboreum*, Knight (1948a) reported the occurrence of a major gene $\mathbf{B_4}$, accompanied by a strong complex of minor genes responsible for blackarm resistance of the variety Multani. In addition Knight (1953b) discovered the occurrence of a blackarm resistance intensifier, $\mathbf{B_{6m}}$, in the same species. The minor genes in *arboreum* are reported to reduce the frequency of blackarm lesions with little corrresponding effect on lesion size (Knight and Hutchinson, 1950). In *herbaceum*, blackarm resistance is similarly controlled by a strong gene $\mathbf{B_9}$, fortified by a number of minor genes (Knight, 1956). Kulkarni and Patel (1951) have, on the other hand, recorded the existence of a partly dominant gene for blackarm susceptibility in *herbaceum*. In a perennial variety of *barbadense*, blackarm resistance was found to be due to yet another gene $\mathbf{B_5}$, variable in expression but fortified by minor genes (Knight, 1950). Again the same author, Knight (1954a) found that a recessive gene $\mathbf{b_8}$ controlled the blackarm resistance in *anomalum*.

The blackarm resistance genes have been grouped into two categories by Knight and Hutchinson (1950). In one group are those that have no demonstrable effect on the plant apart from giving resistance to blackarm, e.g., $\mathbf{B_2}$, $\mathbf{B_3}$, $\mathbf{B_4}$ and $\mathbf{B_5}$. They are preadaptive in the sense that they are without selective value in the absence of the disease. In the second category are genes which affect the plants in other ways and only incidentally confer or enhance blackarm resistance. There are important differences between types of cotton in the rate at which leaf and stem tissues harden off. Quick hardening types are susceptible to the disease for a short period only as they tend soon to develop a stage where lesion growth is inhibited. Moreover, rate of hardening depends largely on the external environment, so that a naturally quick hardening type in a climate favouring rapid hardening may be highly resistant to blackarm. Rapid leaf hardening is commonly found in cottons from areas subject to high winds and/or prolonged periods and low humidity, and is presumably a response to the selective effect of the climate. Its effect on blackarm resistance is purely secondary.

Resistance to Wilt. Fahmy (1931, 1934) carried out investigations in Egyptian cottons on the inheritance of resistance to wilt disease. He started with the hypothesis that the resistance was controlled by a single factor pair. Later studies, however, indicated multiple factor inheritance.

Hutchinson, Gadkari and Ansari (1938) discussed the results of Fahmy and postulated a simple scheme on multiple factor theory of inheritance, which could satisfactorily cover up all data.

Uppal, Kulkarni and Randive (1941) found evidence of monohybrid segregation for wilt resistance in F_2 generation of a cross between two varieties of *herbaceum*, K. F. and 1027A L. F. In crosses within *arboreum*, however, involving the *bengalense* type Dhulia 2 and the *sinense* types Chinese 51 and N. M. D. the resistance character appeared to involve three complementary factors.

Kelkar, Chowdhari and Hiremath (1947c), working with varieties belonging to *herbaceum* found that the resistance to *Fusarium* wilt at Dharwar is controlled by two dominant complementary genes, $\mathbf{W_1}$ **(A)** and $\mathbf{W_2}$ **(B)**. Another gene discovered in the material studied was $\mathbf{W_3}$ **(C)**, a resistance inhibitor.

PLEIOTROPY

The designation of genes is a matter of convenience and the symbols indicate only the prominent character effects produced by the genes. These symbols, therefore, need not be regarded as giving a complete account or description of the total range of effects produced by the various genes in a plant. In fact a number of genes, commonly known as pleiotropic ones, effect more than one character of the plant body.

In cotton most of the deleterious mutants, like $\mathbf{m_2}$ ($\mathbf{m^b}$), multi-bracteolate; **pte**, pistillate; **ls** (**s**), entire leaf and others, affect more than one part of the plant. Outstanding cases of pleiotropism in cotton could be briefly summarised as follows.

1. Glabrous lintless genes $\mathbf{h_a}$ and $\mathbf{h_b}$: these genes make the entire plant body glabrous and waxy; they also bring about lintlessness of the seed and adversely affect the petal development.
2. Punjab hairy lintless gene $\mathbf{li_c}$ controls plant height besides lintlessness. Ramiah and Kaiwar (1942), and Gadkari and Ramiah (1952) have shown that this gene affects viability, and slows down the general growth rate, so that plant height, components of leaf shape, internodal length, lint development are all adversely affected.
3. Silow (1941) reported that the anthocyanin gene $\mathbf{R_3^{GO}}$ governing spotlessness of petals in *anomalum* is also characterised by pleiotropic gold petal expression.

LINKAGE

It is often noted in genetic studies that two or more distinctly different plant characters often go together. This may be due to: (*i*) pleiotropism as already described; (*ii*) location of two or more genes close together on the same chromosome, i.e., due to their close linkage so that there is a tendency for recurrence of their combination more frequently; or (*iii*) the

combined action of the above two phenomena whereby a close correlation or constant degree of association is shown by two or more characters in course of heredity.

Several instances of linkage are known in cotton. Table 74a, reproduced from Knight (1954c), indicates the known linkage groups in the Old World and the New World cottons. The degree of linkage and cross-over values for each of the linkage groups are briefly summarised in the table.

TABLE 74a. GENE LINKAGE IN *Gossypium*—OLD WORLD COTTONS

Group	Linkage group and cross-over value		References
1 *a.*	L : cu : Lc_1		
	——16·6——	*G. arboreum*	Yu, 1939b
	——15——19——	*G. arboreum*	Silow, 1944b
	——28·7——	*G. arboreum*	,,
	——29·9——	*G. arboreum*	Hutchinson, 1934
	——27–32——	*G. arboreum*	Cuany (Unpubl.)
	——24·5——	*G. arboreum* x *G. herbaceum*	Silow, 1944b
b.	L : Li_d : Lc_1		
	——17·1——20·5——	*G. arboreum* x	Govande, 1944b, 1948
	——26·9——	*G. herbaceum*	Hutchinson, 1935
c.	This chromosome carries a fuzz modifier		
2	H_a : Lc_2		
	——7·1——	*G. arboreum* x *G. herbaceum*	Silow, 1944b
3	Y_e : Lc_3		
	——24——	*G. arboreum* x *G. herbaceum*	,,
4	P_b : Ne		
	——16——	*G. arboreum*	Govande, 1940 Cuany (Unpubl.)
	——3·5–5·6——	*G. arboreum* x *G. herbaceum*	,,
5 *a.*	P_a : Ydp		
	——29·7——interspecific		Silow (Unpubl.)
b.	P_a : modifiers of Lc_2		Silow, 1944b
6	R_3 : Y_b		
	——1·2——interspecific		Silow (Unpubl.)
7 *a.*	Chl_2 : R_2 : Cl		
	——30——	*G. herbaceum*	(Linear order not implied) Patel, Munshi and Patel, 1947: Yu, 1939a
	——9——	*G. arboreum*	
b.	R_2 : wilt resistance		Ramiah and Paranjpe, 1947
c.	R_2 : b_8		
	——1·4——		Knight, 1954a
8	Fz : lint length: seed weight		(Linear order not implied) Hutchinson,1935
9	h_b : protruding stigma		Afzal and Singh, 1932
10	Y_a : petal length		Hutchinson, 1931

See note to Table 75.

TABLE 74b. GENE LINKAGE IN *Gossypium*—NEW WORLD COTTONS

Group		Linkage group and cross-over value				Reference
1	*a.*	R_1	:	cl_1		
		——13·9——				Harland, 1934c
		——16——			intra-specific	Loden, 1950
		——8——			interspecific	„
		——18·5——				Neely, 1942
		——14·1-19·6——				Silow, 1944b
	b.	R_1	:	low lint index		Thadani, 1923: Ware, 1941b
2		R_2	:	cl_2		Silow, 1946
		——10·4——				„
3		H_1	:	chl_1		Knight and Sadd, 1954
4	*a.*	H_2	:	short lint		Simpson, 1947: Knight and Sadd, 1953
	b.	H_2	:	lint colour *G. tomentosum* crosses		Hutchinson, 1946c
		H_2	: nankeen lint			Stephens (Unpubl.)
5	*a.*	Cr	:	Lg		
		——5——				Harland, 1934c
	b.	Lg	:	high wax content: fineness (linear order not implied)		Conrad and Neely 1943: Ware, 1932
	c.	Cr	:	ck		Stephens, 1950a
6		B_1	:	d_1		Knight, 1947b
7		B_2	:	B_3		
		——32——			interspecific	Knight, 1944b
		——50——			intra-specific	Knight, 1944b (Cuany-Unpubl.)
8		$Lc_1{}^M$	:	shortened lint		Yang, 1945
9	*a.*	V_5	:	Fgr		„
	b.	V_5	:	green leaf		

See note to Table 75.

In addition to the linkage groups included above for the Old World cottons, Hutchinson (1932, 1934) presented evidence showing that genes affecting lint length, seed weight and node number of the primary sympodium are present in the chromosome carrying the **R** locus. One or more genes responsible for low 'node number' are also reported to be carried by **Y** and **L**—$\mathbf{Lc_1}$ chromosomes. In *herbaceum*, Bhat and Desai (1956) have reported that cluster and whorled are linked complementary loci, situated at about 30 and 11·3 recombination percentages, respectively, on the same side of anthocyanin locus $\mathbf{R_2}$. Closely linked with the whorled locus, $\mathbf{loc^{2\text{-}3}}$. In the same species, they (1955) have also reported that the genes for curled (**cu**) and pale green leaf are located on the same chromosome, recombination percentage being *c*.22·5. With this discovery the gene for pale green leaf is included in the linkage group consisting of the genes for: (*i*) leaf shape; (*ii*) lint colour; (*iii*) curled leaf; and (*iv*) lintlessness.

It will be seen from Table 74b that Loden (1950) reported two different linkage values for the loci $\mathbf{R_1}$ and **cl** in inter and intraspecific hybrid material. The absence of cross-over individuals in the expected numbers in *hirsutum-barbadense* cross was attributed to cryptic cytological differences.

Stephens (1955) has recently recorded the linkage relationships for the mutant genes in Uplands (*hirsutum*). These mutants fall into a maximum of eleven linkage groups as follows :

1. $\mathbf{N — Lc_1 — yg^2 — Cl_2 — R_2}$
2. **L — Cr — Lg**
3. $\mathbf{R_1 — cl_1}$
4. $\mathbf{H_2 — Lc_2}$
5. to 11. **cn, cu, fg, P, Rd, v** and $\mathbf{y_1}$

The remaining 15 chromosomes of the total set of 26 were thus unmarked. Six loci could be placed in the D_h genom and seven others in the A_h genom of Uplands. Stephens has remarked that mapping of *hirsutum* chromosomes in this way should make possible a critical examination of the initial chiasma frequency during meiosis. The first linkage group given above seemed to be in agreement with the hypothesis of one chiasma in each arm of the chromosomes in *hirsutum*; double cross-overs being non-existent. Studies of Rhyne (1957) have led to the extension of the reported $\mathbf{R_1\text{-}cl_1}$ linkage group in the D genom of *hirsutum* to four loci: $\mathbf{R_1\text{-}cl_1\text{-}yg_1\text{-}dw}$. This is considered to be a duplicate of that reported in the A genom: $\mathbf{R_2\text{-}cl_2}$ - $\mathbf{gy_2\text{-}lc_1\text{-}n}$. The gene order is not necessarily duplicated in the two linkage groups. The duplicate genes for yellow green $\mathbf{Yg_1}$ and $\mathbf{Yg_2}$ showed estimated linkage value of 20 per cent. with $\mathbf{R_1}$ and $\mathbf{R_2}$ (Rhyne, 1957; Stephens, 1955). The **Dw** locus was calculated to show linkage with $\mathbf{R_1}$ of *c*.27 per cent. (Rhyne, 1957).

COMPARATIVE GENETICS AND INTERSPECIFIC HOMOLOGIES BETWEEN GENE LOCI

It is of interest from the evolutionery as well as plant breeding point of view to obtain information on the interspecific homologies of the various gene loci, particularly of those existing in the tetraploid species and the two diploid groups of species from which the tetraploids were presumably derived. Several of the genes in **Hirsuta** species have been located in the constituent A or D genoms. Homologies of some of those located in the A genom with similar genes discovered in the Old World species have also been proved (Table 75) with the help of suitable genetical experiments including transfer of genes from one species to another by backcrossing (Harland, 1936a; Harland and Atteck, 1941a; Knight, 1952, 1954a, 1955).

Critical genetic analysis for the determination of interspecific homologies requires the synthesis of fertile hybrid combinations. Stephens (1954), however, has tackled this problem of comparative genetics in a different way with regard to the pollen and corolla colour loci. As a working hypothesis he assumed that similar loci in different species of a genus control basically similar mechanisms. This assumption implied nothing regarding the cytological homology of the gene loci. With this as a starting point, known genetic relations in the diploids were used by Stephens to survey the probable genetic relations in the tetraploids of *Gossypium*. The initial steps in the investigation did not necessitate the production of fertile hybrid combinations nor the analysis of segregating populations.

Pollen Colour Loci. The reported genotypes for cream pollen in *anomalum* and *hirsutum* are $\mathbf{P_a\ P_b}$ and $\mathbf{p}$, respectively. Since their hybrid also possessed cream pollen, Stephens considered it likely that cream pollen *hirsutum* does not carry a '$\mathbf{P_a}$ type' gene, i.e., a gene homologous with $\mathbf{P_a}$, a duplicate of $\mathbf{P_a}$, or merely a gene which includes a '$\mathbf{P_a}$ like' process among its functions. The genotype for cream pollen *hirsutum*, therefore, is either $\mathbf{P_a\ P_b}$ or $\mathbf{p_a\ p_b}$. Of these alternative genotypes $\mathbf{P_a\ P_b}$ is only one step removed from full yellow pollen colour, $\mathbf{P_a\ P_b}$, while $\mathbf{p_a\ p_b}$ should require two steps. Because pollen colour in **Hirsuta** species is controlled by a single pair of alleles **P** and **p** (Harland, 1929), it was further considered likely that genotype for cream pollen *hirsutum* is $\mathbf{p_a\,p_b}$ and for yellow pollen *hirsutum*, $\mathbf{P_a\,P_b}$. In other words, Stephens suggested that the **P** locus is probably equivalent to (if not homologous with) $\mathbf{P_a}$ locus in **Herbacea** and *anomalum*. Potentially, therefore, there could be four loci for pollen colour in tetraploid species—two in the A genom and two in the D genom—yet the character seemed to be governed by changes at only one locus (**P**), probably of the '$\mathbf{P_a}$ type'. Pollen is yellow in presence of $\mathbf{P_a}$ and cream in absence of $\mathbf{P_a}$. On the other hand, the possibility of the step symbolized by **P** in **Hirsuta** being equivalent to both $\mathbf{P_a}$ and $\mathbf{P_b}$ acting jointly as a unit was also pointed out. The loci **P** and $\mathbf{P_a}$ of *hirsutum* and *arboreum* were found to be homologous

with each other in the study of pollen colour inheritance in the tri-species hybrid, hexaploid (*hirsutum-arboreum*) x *raimondii.*

Following similar reasoning, it was suggested that the diploid species possessing cream pollen in the following cross combinations also lack a '$\mathbf{P_a}$ type gene' because none give complementary yellow pollen hybrids on crossing with *hirsutum* or *anomalum:*

cream pollen *hirsutum* x *sturtii,*
anomalum x *thurberi,*
anomalum x *aridum,*
aridum x *thurberi,* and
thurberi x *klotzschianum.*

The probable genetic constitution of the diploid parents was put as $\mathbf{p_a}$ $\mathbf{p_b}$ or $\mathbf{p_a}$ $\mathbf{P_b}$ (unless both loci were missing from their respective genoms).

Corolla Colour Loci. With regard to corolla colour in *arboreum, herbaceum* and *anomalum,* existence of triplicate complementaries has been reported. When such complementary genetic types exist, each may be used as a tester to determine the presence or absence of the other complementary gene in any type with which it will cross. The genotypes, *arboreum* white ($\mathbf{Y_a}$ $\mathbf{Y_b}$ $\mathbf{Y_c}$) and *anomalum* Pale ($\mathbf{Y_a}$ $\mathbf{Y_b}$ $\mathbf{Y_c^p}$) have been hybridized extensively with other species possessing non-yellow petals. The F_2 hybrid of *arboreum* white with *hirsutum* Pale, *thurberi, aridum* or *raimondii* show complementary yellow corolla. It was, therefore, suggested by Stephens (1954), that the non-*arboreum* parents in these crosses carry a gene of '$\mathbf{Y_a}$ type'. The hybrids of *anomalum* pale with *hirsutum* pale, *thurberi* and *raimondii* possess pale corolla, indicating thereby that none of the other parents carry a gene of the '$\mathbf{Y_c}$ type', the single step necessary to convert *anomalum* pale to yellow. Thus, the genotype arrived at for *hirsutum* pale for two of the three complementary loci was $\mathbf{Y_a}$ $\mathbf{Y_c^p}$. For establishing its constitution in respect of $\mathbf{Y_b}$ locus, its reaction with *arboreum* Chinese pale ($\mathbf{Y_a}$ $\mathbf{Y_b^p}$ $\mathbf{Y_c}$) would have been helpful. In the absence of this information, Stephens (1954) argued that if the *hirsutum* pale were genotypically $\mathbf{Y_a}$ $\mathbf{Y_b}$ $\mathbf{Y_c^p}$, a single step only would be necessary to convert it to yellow (substitution of $\mathbf{Y_c^p}$ by $\mathbf{Y_c}$); two steps would be necessary for the genotype $\mathbf{Y_a}$ $\mathbf{Y_b^p}$ $\mathbf{Y_c^p}$ to get converted to yellow. It is known that either of the two steps is enough to convert *hirsutum* pale to yellow since the corolla colour is governed by the duplicate loci, $\mathbf{Y_1}$ and $\mathbf{Y_2}$. Stephens, therefore, considered it likely that *hirsutum* pale has the genotype $\mathbf{Y_a}$ $\mathbf{Y_b}$ $\mathbf{Y_c^p}$ and that $\mathbf{Y_1}$ (or alternatively $\mathbf{Y_2}$) was equivalent to *arboreum* $\mathbf{Y_c}$. This apparent equivalence did not imply genetic homology, nor did it rule out the possibility that the $\mathbf{Y_1}$ and $\mathbf{Y_2}$ genes in *hirsutum* are each equivalent to *arboreum* $\mathbf{Y_b}$ and $\mathbf{Y_c}$ acting jointly. Homology of $\mathbf{Y_1}$ and $\mathbf{Y_c}$ loci became evident from the genetic investigations on the tri-species hybrid, hexaploid (*hirsutum-arboreum*) x *raimondii.*

The hybrids of *hirsutum* Pale (Y_a Y_b Y_c^P) with *thurberi*, *aridum*, *raimondii* and *gossypioides* possess pale corolla. Stephens, therefore, inferred that these New World diploid species probably lack Y_c. For the present there is no evidence for two or more types of non yellow corolla colour in the D genom as in the A genom.

Gossypium sturtii contains a large amount of anthocyanin in its flowers which effectively masks the favourable present and results in a purplish mauve colour. In the F_1 (*arboreum* white x *sturtii*), the petal colour is shifted towards red and becomes a pale magenta. One of these hybrids treated with colchicine developed large mosaic sectors (Stephens, 1954). Many of the sectors lacked anthocyanin. Such sectors on the petals were yellow and not white. Stephens, therefore, inferred that the hybrid is genotypically complementary yellow although normally masked by the anthocyanin present in the corolla. Petal colour in *hirsutum* pale x *sturtii* hybrid differs little from that of *sturtii*. Anthocyanin free extracts of the petals in the parental species and hybrids yield cream coloured precepitates on evaporation. Stephens, therefore, concluded that *hirsutum* pale x *sturtii* hybrids are genotypically pale like their parents.

INHERITANCE IN SYNTHETIC POLYPLOIDS

Inheritance studies have been carried out to a limited extent in some of the artificially induced alloploids of *Gossypium*. In any study of genetical segregation it is important to see whether any appreciable abortion occurs in the material and then it is necessary to ascertain to what extent the ratio may be biased by differential survival. Some of the observations made on this subject by Gerstel (1956) are given below. In the allohexaploid (*hirsutum* x *raimondii*) a large majority of bolls fall off at varying intervals between pollination and maturity. In *barbadense-raimondii* hexaploids a little more than half of the pollinated bolls stayed on, which also seemed to be the case with the *hirsutum-thurberi* hexaploid. The loss of bolls was ascribable to physiological abscission common even in pure species of *Gossypium* and pronounced during certain periods than in others in both species and hybrids. The fact considered more significant genetically was that only a few seeds in each boll reached maturity whereas the majority aborted at various stages during development. The number of germinable seeds per boll did not fit any random distribution as it would, were the chance for an embryo to reach maturity independent of others and dependent on its genotype only. Presumably, physiological factors, such as, developing seeds stimulating development of neighbouring ones (Weaver, 1955b) were also operative in determining the number of seeds in a boll. In all the aforementioned alloploids, male sterility was also high.

Keeping in view these factors causing elimination of some genotypes, Gerstel (1956) studied segregation for anthocyanin (petal spot and plant

body) colour in the above alloploids, which according to the scheme given by Stebbins (1947), belong to the segmental alloploid category. The genes involved were :

1. **R** producing red pigment in the plant body and on the margin of the petals but no petal spot.
2. $\mathbf{r_1}$ allelic to $\mathbf{R_1}$ producing green plant body.
3. $\mathbf{R^{THU}}$ producing a variable red spot at the base of the petal characteristic of *thurberi* (the spot does not appear in hybrids with *hirsutum*).
4. $\mathbf{R^{RAI}}$ allelic to $\mathbf{R_1}$ (Rhyne, 1951) producing a large deep carmine spot, 'RAI spot' at the bottom of the petals characteristic of *raimondii*; filaments and base of androecium being similarly coloured ($\mathbf{R^{RAI}}$ dominant in interspecific combination).

In the cross, hexaploid (*hirsutum* x *raimondii*) x *hirsutum* some families belonging to one of the following two genotypic combinations were obtained:

$$\mathbf{R_1 \quad R_1 \quad R^{RAI} \quad R^{RAI}} \times \mathbf{r_1 \quad r_1}$$
$$\mathbf{r_1 \quad r_1 \quad R^{RAI} \quad R^{RAI}} \times \mathbf{r_1 \quad r_1}$$

All but one of the families comprised plants phenotypically belonging to RAI spotted and RAI spotless categories in the ratio of 8:68:1. From the cross, hexaploid (*hirsutum* x *thurberi*) x hexaploid (*hirsutum* x *raimondii*), genotypically $\mathbf{R_1\ R_1\ R^{THU}\ R^{THU}} \times \mathbf{r_1\ r_1\ R^{RAI}\ R^{RAI}}$ nearly similar ratio of phenotypes was obtained. With random assortment of $\mathbf{R_1}$ or $\mathbf{r_1}$ and $\mathbf{R^{RAI}}$ due to random segregation of the chromosomes concerned, the ratio of RAI spotted to RAI spotless plants would be 5:1. The results obtained differed significantly from this ratio and also from a true alloploid segregation ratio of all RAI: none non-RAI resulting from 'homogenetic' (see Waddington, 1939) pairing between chromosomes derived from the same parent species. The findings were actually intermediate between the two expectations. But for one exception, the spotless plants were uniformly fewer than would be expected with randomness regardless of the genetic line, or even species, of the New World diploids used in the synthetic hexaploid.

The segmental alloploids, as is usual for newly synthesized polyploids, were also partially fertile and whether the observed deviation from 5:1 were a reflection of meiotic behaviour or due to post-meiotic selection had to be considered. Only indirect attacks were possible. From the genetic results it would seem that 'heterogenetic' conjugation between D_h and D_5 genom chromosomes was far from random because the male and female gametic ratio of the genotype, $\mathbf{r_1\ r_1\ R^{RAI}\ R^{RAI}}$ (hexaploid—*hirsutum* x *raimondii*), was 8·68 RAI: one non-RAI. This observed ratio could have been effected by partial homogenetic pairing within D_h or D_5 genoms associated with some degree of heterogenetic pairing between the two genoms. Such a conclusion, however, would be based on the assumption that little selective elimination of the non-intermediate types ($\mathbf{R_1\ R_1}$ and $\mathbf{R^{RAI}\ R^{RAI}}$) occurred at

post-meiotic stages. Male and female gametic elimination was certainly considerable, and zygotes were also eliminated at all seed and seedling stages. But all this sterility appeared to be random as far as the different alleles at the $\mathbf{R}_1$ locus were concerned because the aforementioned crosses using the hexaploid (*hirsutum-raimondii*) as male or female parent gave similar segregation and it is unlikely that discrimination against pollen and eggs of a certain genotype is the same despite their entirely different conditions.

Comparison on the frequencies of the $\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}$ and $\mathbf{R}_1\ \mathbf{R}_1$ classes (where both could be distinguished in the progeny of the genetic model, **A A a a** with respect to the genes $\mathbf{R}^{\mathrm{RAI}}$ and $\mathbf{R}_1$) was also made with the object of determining whether there was any selective elimination in any one of them. In the cross $\mathbf{R}_1\ \mathbf{R}_1\ \mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}$ x $\mathbf{r}_1\ \mathbf{r}_1$, detailed classification of the segregates was made. On the basis of normal two by two disjunction of the four alleles present in the hexaploid parent three types of eggs were expected: $\mathbf{R}_1\ \mathbf{R}_1$; $\mathbf{R}^{\mathrm{RAI}}$ and $\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}$. These on fertilization by sperms carrying $\mathbf{r}_1$ were expected to give zygotes of the constitution $\mathbf{R}_1\ \mathbf{R}_1\ \mathbf{r}_1$ (deep red plant body, no RAI spot), $\mathbf{R}_1\ \mathbf{R}^{\mathrm{RAI}}\ \mathbf{r}_1$ (intermediate red body and RAI spot) and $\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}\ \mathbf{r}_1$ (green body and deep RAI spot with pigmentation at the base of the androecium). Actually these three types of zygotes formed the bulk of the progeny ; in addition of few offspring suggested numerical non-disjunction in the mother parent. Among the three major classes, it was noticed that more plants came from $\mathbf{R}_1\ \mathbf{R}_1$ than from $\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}$ gametes; the difference was below one per cent. level of probability and suggested that offspring carrying the two *hirsutum* alleles $\mathbf{R}_1\ \mathbf{R}_1$ were obtained somewhat more often than offspring with two alleles from *raimondii* ($\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}$). It could not be decided whether elimination took place at the gametic or zygotic stages. The observation is suggestive of the discrimination which Stephens (1949) found in back-crosses of the *barbadense-hirsutum* hybrids to both the parental species. There occurred a tangible deviation from a 1:1 ratio which tended to favour the alleles derived from the recurrent parent. Thus there were indications that some post-meiotic elimination of certain genotypes occurred but this was not of very high order.

The zygotes $\mathbf{R}_1\ \mathbf{R}_1\ \mathbf{r}_1$ and $\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}\ \mathbf{r}$ were again test crossed with *hirsutum* $\mathbf{r}_1\ \mathbf{r}_1$. The recessive represented nearly one-fourth of the progenies in the former case and less than one-seventh in the latter case. This was attributed to random assortment in the case of the genotype $\mathbf{R}_1\ \mathbf{R}_1\ \mathbf{r}_1$ which possessed all three chromosomes of *hirsutum* origin excepting segments exchanged by crossing over. In the case of the genotype $\mathbf{R}^{\mathrm{RAI}}\ \mathbf{R}^{\mathrm{RAI}}\ \mathbf{r}_1$, Gerstel (1956) suggested the occurrence of preferential pairing between the two *raimondii* chromosomes which increased the proportion of gametes with $\mathbf{R}^{\mathrm{RAI}}$. This is genetic evidence for differential pairing of at least one of the chromosome pairs of *raimondii* in presence of a corresponding 'homo-

logue' from *hirsutum*. The differential pairing inferred from the available data may be presumed to have been caused by cryptic structural difference in the corresponding chromosomes derived from different species.

Inheritance of plant body colour was studied in the crosses of the hexaploid ($\mathbf{R_1}$ $\mathbf{R_1}$ *hirsutum* x $\mathbf{R^{THU}}$ $\mathbf{R^{THU}}$ *thurberi*) with $\mathbf{r_1}$ $\mathbf{r_1}$ *hirsutum* and with the hexalploid ($\mathbf{r_1}$ $\mathbf{r_1}$ *hirsutum* x $\mathbf{R^{RAI}}$ $\mathbf{R^{RAI}}$ *raimondii*).

The ratio of gametes with $\mathbf{R^{THU}}$ to those without $\mathbf{R^{THU}}$ was 67·1:1. Corresponding ratio of gametes in regard to $\mathbf{R^{RAI}}$ was 8·68:1 in the inheritance of the hexaploid (*hirsutum* x *raimondii*). On comparing the segregation for $\mathbf{R_1}$-$\mathbf{R^{RAI}}$ alleles in these studies, it was noticed that *c*. 84 per cent. plants originated from $\mathbf{R_1}$ $\mathbf{R^{THU}}$ eggs whereas much as *c*. 97 per cent. plants originated from $\mathbf{R_1}$ $\mathbf{R^{THU}}$ eggs in the respective hexaploids. From these observations it was clear that the segregation ratio in the hexaploid *hirsutum-raimondii* was narrower than that in the hexaploid *hirsutum-thurberi*. It was suggested by Gerstel that this could be indicative of a closer taxonomic relationship between **Hirsuta** cottons and *raimondii* than between the former and *thurberi*. Earlier morphological studies had given similar indications (Stephens, 1944c ; Hutchinson, Stephens and Dodds, 1945).

Differences in genetic segregation of the hexaploid involving *hirsutum* on the one hand and *thurberi* or *raimondii* on the other, thus suggest that at least the chromosomes carrying $\mathbf{R_1}$ or $\mathbf{r_1}$ loci do not pair to the same extent with the corresponding chromosomes bearing the loci $\mathbf{R^{THU}}$ or $\mathbf{R^{RAI}}$. This may be surprising in view of the fact that the chromosomes of the two wild species are homologous to the extent of forming 13 bivalents in many pollen mother cells of their hybrids with each other and with the **Hirsuta** species (Tables 58 and 61). The genetic segregation in alloploids has thus revealed differences between the chromosomes of the parental species which would not be easily detected by a cytological inspection of the F_1 hybrids.

Several synthetic alloploids combining various species and containing contrasted genetic markers were crossed to recessive testers by Gerstel (1953b). The segregation ratios reflected, in part, but not entirely, known taxonomic relationships. Thus, tetraploid *arboreum-herbaceum* gave tetrasomic ratios for pollen colour, plant anthocyanin, leaf shape and Red lethal. Tetraploid *anomalum-arboreum* gave only rare segregants; segregation for corolla colour, anthocyanin and leaf shape was restricted. Homogenetic pairing was, therefore, considered to be strong though not complete. From amphiploid *arboreum-thurberi*, no segregation was obtained for anthocyanin, pollen colour, corolla colour and leaf shape factors. Comparison of the hexaploids from crosses of *hirsutum* with *thurberi* and *raimondii* was of special interest. Comparative segregation at $\mathbf{R_1}$ locus in them and its significance has been given earlier. Similarly segregation at the leaf shape locus was relatively most frequent in the hexaploid *hirsutum-raimondii* (27 narrow: 390 intermediate: 34 broad) than in the hexaploid *hirsutum-thurberi* (6: 110: 3).

Inheritance in the tetraploid hybrid obtained by cross hexaploid (*hirsutum* x *arboreum*) with *raimondii* has been studied by Stephens 1954 with the object of determining interspecific homologies between gene loci governing colour of petals caused by flavonols and pollen.

The *hirsutum* and *raimondii* components of the hybrid had pale corollas. The genotypic constitution assumed for them by Stephens (1954) on the bases of his investigations on comparative genetics was, $Y_a\ Y_b$ (or $Y_b{}^P$) $Y_c{}^P$. The *arboreum* component was yellow-flowered, genotypically $Y_a\ Y_b\ Y_c$. On this basis segregation at the Y_c locus was definitely expected in backcrosses to *hirsutum*. Whether or not segregation should occur in the Y_a and Y_b loci would depend on their location and/or level of duplication in *hirsutum*. Even with complete homology between the corresponding genoms there is clearly a possibility of six loci being involved in *hirsutum*.

The segregations in the first test cross progenies were consistently and clearly monofactorial (1 Yellow: 1 Pale) indicating segregation at Y_c locus alone. In the second backcross generation, yellow heterozygotes ($Y_c\ Y_c{}^P$) of the first backcross generation were crossed with a tester *hirsutum* heterozygote ($Y_1\ Y_1$). If Y_c and Y_1 loci were homologous, then Y_c and Y_1 should be either identical or allelic and the hybrids obtained should be of three types: (*i*) homozygous yellow ; (*ii*) heterozygous for yellow and pale ; and (*iii*) homozygous pale in the ratio of 1:2:1. These classes were actually obtained in proportions agreeing reasonably well with those expected on the monofactorial basis. If duplicate loci were involved, then all of the apparently homozygous yellow families would have to be heterozygous and segregating in a 15:1 ratio. Two of the selfed progenies of the second backcross generation were above the minimal size (47 plants) for the chance exclusion of one or more pale segregates at the 5 per cent. level of probability. With three or more loci, the family sizes in the apparently homozygous yellow class were not large enough to detect pale segregates. However, with three loci involved the proportion of homozygous pale progenies to the total should be much smaller than that actually obtained, in the earlier test cross. It was, therefore, clear that monofactorial hypothesis was the only one which could fit the data satisfactorily. In the progenies segregating for yellow and pale there was an overall defficiency of yellow segregates, the actual ratio being 2·3 yellow: 1 pale. This deviation from 3:1 ratio was considered to be probably due to selection against the *arboreum* chromosome carrying Y_c.

As regards pollen colour, the *arboreum* component in the tri-species hybrid studied by Stephens (1954) was genotypically yellow: $P_a\ P_b$. Based on his studies on comparative genetics, the genotypes for cream pollen in *hirsutum* and *thurberi* were assumed to be $P_a\ P_b$ and P_a, respectively. The situation regarding P_b in the latter case was considered to be uncertain. The tri-species hybrid was thus assumed to possess only one P_a gene. Its backcross to tester lines of *hirsutum* possessing cream pollen showed segregation into

yellow and cream classes. The frequencies of the classes were in statistically acceptable agreement with the monofactorial test cross ratio 1:1.

In order to test for the homology of the **P** locus, some yellow segregates in the first backcross were crossed to yellow *hirsutum* types known to be heterozygous for the **P** locus. Selfed progenies of these second backcross plants either bred pure for yellow or cream or segregated for the two contrasting features. The proportions of these progenies were clearly in agreement with the monofactorial ratio expected on crossing two types heterozygous for the same gene. If the yellow genes from the tri-species hybrid and from the heterozygous *hirsutum* parents in the second backcross were carried at duplicate loci, no homozygous lines should have been obtained. It was thus concluded that a gene determining yellow pollen introduced from *arboreum via* the tri-species hybrid into *hirsutum*, is identical or allelic with the gene determining yellow pollen in *hirsutum* and other tetraploid species. The **P** locus of **Hirsuta** species (Harland, 1929a) is thus carried in the $\mathbf{A_h}$ genom according to Stephens (1954). Stephens has also stated that a critical and direct test of his inferences would be given by the cross, pale *arboreum* $\mathbf{P_a}$ $\mathbf{P_b}$—cream *hirsutum* $\mathbf{P_a}$ $\mathbf{P_b}$. If it proves to be complementary yellow it would confirm the given interpretations.

Since the same tri-species hybrid was used for location of the pollen colour locus, $\mathbf{P_a}$, and the corolla colour locus, $\mathbf{Y_1}$, linkage test could be applied in progenies segregating for both the characters. The results showed complete independence of the two loci despite the reported association of yellow pollen and corolla or cream pollen and pale corolla in all *Gossypium* species excepting *stocksii* which had cream pollen and yellow corolla.

Richmond (1951) has reported on the inheritance of fibre strength character in crosses of the tetraploid (*arboreum-thurberi*) with *hirsutum*. Results obtained in Texas (U.S.A.) indicated that the character is inherited quantitatively; some of the genes being dominant and others recessive.

A number of striking instances of leaf colour, petal spot and petal colour mosaics have been noted in what are termed as 'polygenomic hybrids' (see hexaploid hybrid combinations in chapter VII) involving three or four species (Menzel and Brown, 1952b). Mosaicism was a characteristic morphological feature in some, while in others it occurred sporadically. Certain markedly and uniformly mosaic polygenomic hybrids were derived from allohexaploid parents in each of which very little, if any, intergenomic pairing occurs (Brown and Menzel, 1952a). Menzel and Brown (1952b), therefore, ruled out the possiblity of meiotic crossing over of genes into heterochromatic regions of another genom causing mosaicism. Since at least three sets of characters were affected, each probably involving several different loci in each genom, increased mutation rate due to hybridity also seemed unlikely to be the cause. Two clear cases of somatic reduction have been reported by Menzel and Brown (1952b) and Menzel (1952) in mosaic forming allohexaploid hybrids.

Some sort of atypical mitotic separation has, therefore, been indicated as the cytological basis of mosaicism. Huskins and his co-workers have demonstrated that the frequency of abnormal mitosis having one or more features of meiosis can be altered by chemical and physiological means. Hence, Menzel and Brown consider it plausible that the increase of mosaicism with increasing chromosome number and genom complexity may be due to progressively greater derangement of the physiological processes controlling normal mitosis.

Leaf shape expression in crosses between the New World tetraploid cottons and wild diploid species has been studied by Balasubrahmanyan (1952b) at triploid and the synthetic hexaploid levels. The leaves of the triploid **Hirsuta**—*raimondii* hybrids were mostly entire like *raimondii*; lobed leaves like the tetraploid parent being present on the nodes of the main stem subtending the branches. In the hexaploid *hirsutum-raimondii*, entire leaves occurred only at the nodes of the secondary fruiting branches carrying flower buds. The influence of the gene **L^E** in the shape expression of entire leaves in the triploid F_1 *barbadense-raimondii* was apparent from the increase noted in length (from centre of callus spot to the tip) and reduction in maximum width of the median lobe. The pattern occurrence of entire leaf in flowering branches at all nodes in triploids and at particular flowering nodes in hexaploids was viewed as having resulted from the timing action of alleles due to the threshold effects of the dominant wild gene present in *raimondii*.

DETERMINANT FOR CROSS INCOMPATIBILITY

Cross compatibility relationships among *Gossypium* species have been summarised in chapter VI. The nature of genetic bases postulated for the different types of incompatibilities met with in this programme of work and the basic or the supporting evidence available for some of the postulates will now be considered.

GENOM 'STRENGTH' RELATIONSHIP

On selfing a species, the genomic ratio of endosperm/zygote is 3:2. Considering this normal value or a value approximating it as essential for interspecific cross compatibility, Stephens (1942), on the basis of his studies with autotetraploid *arboreum*, suggested that two A genoms balance with a single D genom in strength and that the genoms B and E are roughly equivalent to A and C to D, in strength. This 'genom strength balance' hypothesis is probably one of the several mechanisms involved in the ability of the cross combinations to set viable seeds. Crossing behaviour of *anomalum*, *thurberi* and *davidsonii**, however, does not support the hypothesis (Stephens, 1945). Stephens (1945) pointed out the possibility that poor fertilization encountered in the Old World x *thurberi* may be superimposed on the 'balance'

mechanism encountered in the Old World x the New World diploid crosses. The hybrids of *anomalum* are insensitive to 'balance' mechanism encountered in the Old World x the New World diploid crosses. The hybrids of *anomalum* are insensitive to 'balance', which to some extent may account for the ability of *anomalum* to set viable seeds readily when crossed with *davidsonii**—a capacity which is not shared by the other Old World species. According to Stephens (1945), these anomalies would be more readily understood if it could be assumed that *anomalum* and *davidsonii** represent species which have retained affinities both with the New World and the Old World groups. There is some evidence that this may be true in the case of *anomalum*, since phenogenetic studies indicate that its leaf shape development is transitional between **Herbacea** and the New World types. Cross compatibility relationships of *davidsonii** suggest a mechanism not found in the other types.

GENERAL GENOTYPIC RELATIONSHIP

The incompatibility of *klotzschianum* var. *davidsonii* with a number of species has been reported repeatedly and discussed at length (Harland and Atteck, 1931 ; Silow, 1941 ; Stephens, 1942, 1945 ; Brown, 1951). It crosses successfully with *anomalum* and *sturtii.* In crosses with most of the other species it gives large empty seeds inside fully developed mature bolls or inviable off-springs. This is indicative of zygotic incompatibility. When crossed with an F_1 hybrid of a compatible and an incompatible species (*e.g.*, *anomalum-arboreum*) ; it produced seeds six per cent. of which gave viable hybrids. In crosses of *davidsonii** to second and third backcrosses of *anomalum-herbaceum* and *anomalum-arboreum* to *arboreum* and *anomalum*, the percentage of germinable seed increased with the amount of *anomalum* germ-plasm present, as indicated by the expression of the genetic characters tested by Silow (1941). He, therefore, concluded that many factors are involved in incompatibility of *arboreum* and *herbaceum* with *davidsonii**. The incompatibility was attributed to a general genotypic disharmony rather than to the action of specific lethal genes. The disharmony is probably a result of gradual differentiation of the parental genotypes.

MODIFIER COMPLEXES, CRYPTIC STRUCTURAL DIFFERENTIATION OF CHROMOSOMES

Some interspecific crosses like *arboreum* x *herbaceum* and *hirsutum* x *barbadense* give viable and fertile F_1 hybrid but in the F_2 generation a veritable mess of abnormal, unbalanced and sterile types is obtained. The work of Harland (1936a) has shown that long separation among *Gossypium* species has given rise to profound genetical changes in them. Genes have evolved into new alleles, homologous characters have become constructed in different ways, and new co-ordinated 'modifier complexes' set up. 'Modifier complexes' are the stable systems of inter-related oligogenes and polygenes built

up within each species. This genetic balance is disrupted in the segregating generations of the aforementioned cross combinations due to 'multiple gene substitution'. In literature, this phenomenon has been referred to as 'genetic breakdown' or 'genetic erosion' (Harland, 1955c).

Stephens (1949) studied genetically the backcrosses of the *hirsutum-barbadense* hybrid to either of the parents. He noticed a considerable degree of selective elimination of the donor parent genotype in these backcrosses. Since the F_1 hybrid shows good chromosome pairing during meiosis Stephens (1949, 1950b) concluded that in addition to multiple gene substitution, it is necessary to assume small cryptic structural differences between chromosomes of such closely related genoms. The suggestion that sterility in some species hybrids, that show good chromosome pairing at the first metaphase, is often due to cryptic structural differentiation in their chromosome complements originated from Stebbins (1945) and Stephens (1949, 1950b) has suggested that such small structural differences operate in certain *Gossypium* hybrids. The cryptic structural differences to which Stephens refers are considered to involve much smaller 'pieces' of chromosomes than those involved in the gross structural changes which may be recognized cytologically and which may cause partial or total sterility in the hybrid progeny.

It is possible that the selective elimination of the donor parent genotype noticed by Stephens (1949, 1950b) was caused by the particular marker stocks used or by the marker genes *per se*. This possibility was put to test by Lewis and Mc Farland (1952) by using similar marker stocks in intra-*hirsutum* backcrosses. In this material, they did not obtain any selective elimination of the donor parent genotype and, therefore, inferred that the results reported by Stephens (1949) in interspecific backcrosses must have been caused by genic or structural differences between the 'homologous' chromosomes of *hirsutum* and *barbadense*.

SPECIFIC GENES

A few specific genes providing isolation barrier between two *Gossypium* species have been reported by Stephens (1946, 1950a) and Gerstel (1954). In crosses between certain strains of *hirsutum* var. *marie-galante* and *barbadense*, Stephens (*loc. cit.*) found that the genes $\mathbf{ck}^X$ and $\mathbf{ck}^Y$, respectively, in the two parental species are responsible for the deleterious corky effect. He also demonstrated that these two complementary genes are not carried at independent loci; they are carried at very closely linked loci. He suggested that they may be pseudo-alleles because, he argued, that it is more likely for such alleles which have evolved from a common origin, to block the same vital processes than for two independent genes. He further pointed out that croky alleles were especially frequent in strains of the two species which are grown together in mixed cultivation.

Gerstel (1954) reported on the lethality of hybrids obtained from crosses of Sanguineum (*arboreum*) with Upland (*hirsutum*) strains. He used autotetraploid of *arboreum* instead of the natural diploid in order to ensure ready success in crossing it with *hirsutum*. The cross $4n$—Sanguineum x Upland gave all lethal offspring. The $4x$ (Sanguineum x *herbaceum*) x Upland gave a tetrasomic ratio of five lethals : one viable. The $4x$ (Sanguineum x *anomalum*) x Upland gave a total of 252 lethals : six viable plants. The restricted segregation was considered to be a feature of the alloploid parents. From the results it appeared that Sanguineum carried a factor (or linkage group) $\mathbf{Rl}_a$ for 'red lethal'. The symbol $\mathbf{Rl}_b$ was proposed for the factor or chromosome in Upland responsible for lethality. The F_1 (*barbadense*-Upland) produced approximately one lethal : one viable plant in crosses with Sanguineum, indicating thereby that $\mathbf{Rl}_b$ is absent in *barbadense*. The distribution of the determinants $\mathbf{Rl}_a$ and $\mathbf{Rl}_b$ is not reported to be universal in *arboreum* and *hirsutum*. It was also not clear whether they are independent complementaries or alleles with a complementary effect. The two possibilities have been presented by Gerstel (1954) in the following way: in the first case, the formula of diploid Sanguineum should be $\mathbf{Rl}_a\ \mathbf{Rl}_a\ \mathbf{rl}_b\ \mathbf{rl}_b$, that of Upland $\mathbf{rl}_a\ \mathbf{rl}_a\ \mathbf{Rl}_b\ \mathbf{Rl}_b$, and that of their lethal F_1 hybrid $\mathbf{Rl}_a\ \mathbf{rl}_a\ \mathbf{Rl}_b\ \mathbf{rl}_b$ (or $\mathbf{Rl}_a\ \mathbf{rl}_a\ \mathbf{Rl}_b$ if $\mathbf{Rl}_b$ is located in the D genom; the distinction does not affect the following). If the genes were alleles, Sanguineum would be $\mathbf{Rl}_a\ \mathbf{Rl}_a$, Upland $\mathbf{Rl}_b\ \mathbf{Rl}_b$ and their hybrid $\mathbf{Rl}_a\ \mathbf{Rl}_b$. A choice between the two possibilities can be made only by testing the segregation of a lethal hybrid. But even though red lethals may survive long enough to produce some pollen, the lethal types available thus are very highly sterile. Presuming that the amphiploid (Sanguineum x *thurberi*) may give, on crossing with Upland, at least partly pollen fertile F_1 hybrids carrying both $\mathbf{Rl}_a$ and $\mathbf{Rl}_b$, Gerstel suggested that the pollen could be applied to a non-carrier type like *barbadense* for testing the alternative possibilities. In the case of independence of the two complementaries the progeny would comprise plants in the ratio of 3 viable to 1 red lethal and in the case of allelic nature of the two factors the progeny will consist of all viable parents.

The interspecific hybrids of *gossypioides* provide examples of several mechanisms which could serve to isolate species, including hybrid lethality, sterility and asynapsis in F_1 generation. Menzel and Brown (1955) have adduced evidence to show that these mechanisms are all controlled by a few specific genes in the hybrids studied by them.

The crossing behaviour of *gossypioides* has been studied in detail by Brown and Menzel (1952b,c) and Menzel and Brown (1955). Its crosses were readily effected with several natural species (chapter VI) and also with synthetic tetraploids such as $4n$—*arboreum*, $4x$ (*arboreum*-*anomalum*) and $4x$ (*arboreum*-*stocksii*), but the hybrids died either in the cotyledon stage or later after producing several leaves. The lethality was least pronounced in the *hirsutum*-*gossypioides* hybrids, which usually produced a few buds before the charac-

teristic stem-macrosis was fatal. Two exceptions to the general hybrid incompatibility of *gossypioides* were, the hybrid *raimondii* x *gossypioides*, which was vigorous but self sterile and the hybrid *barbadense* x *gossypioides* which proved asynaptic.

The hybrid *raimondii* x *gossypioides* proved male fertile when the 4*x* (*arboreum-stocksii*) was used as a female parent. From the same female viable hybrids were produced by *raimondii* pollen and lethal hybrids by *gossypioides* pollen. It was, therefore, assumed that the functional male gamete of the *raimondii* x *gossypioides* hybrid did not carry the incompatibility factor or factors in *gossypioides*.

The hybrid *thurberi-gossypioides* was lethal and self-sterile but some of the hybrids from the three-species cross (*raimondii* x *thurberi*) x *gossypioides* proved to be viable and self fertile. It was, therefore, considered likely that the lethality and sterility met with in the direct crosses might have a specific genetic basis. If the sterility of viable interspecific hybrids within the New World diploid group were to be attributed to cryptic structural differences in the chromosomes of the parental species, the three-species hybrid, (*raimondii-thurberi*)-*gossypioides*, would be expected to be more sterile than the hybrid *raimondii-gossypioides*. Actually, however, reverse was the case lending support to Menzel and Brown's (1955) postulate that *thurberi* has a gene or genes which are lethal in presence of the *gossypioides* genom, while *raimondii* does not. Conversely, *raimondii* carries a gene or genes which produce F_1 sterility in the presence of *gossypioides* genom, while *thurberi* does not. Segregation in *thurberi-raimondii* hybrid would result in some gametes which carried neither set of factors and hence would form hybrids with *gossypioides* which were both viable and fertile. It was remarked that but for the presence of lethality factors in *thurberi*, its hybrids with *gossypioides* would have been fertile.

In the case of *gossypioides* it appears that interspecific cross incompatibility is similar to that shown by *davidsonii** (chapter VI) in effect, but different in degree, since a greater number of hybrid combinations survive to and beyond the cotyledon stage (Menzel and Brown, 1955). There is, however, no reason to assume *a priori* that incompatibility factors separating *gossypioides* from the other species of the New World diploid group are of the same order as those separating *davidsonii** from the **Herbacea** species. Brown and Menzel (1952c) made a comparative genetic analysis of seedling characters in the small F_2 populations obtained from the hybrids, *thurberi-raimondii* and (*thurberi-raimondii*) x *gossypioides*; their study indicated that genetically simpler mechanism of species isolation may be operating in the case of *gossypioides*.

The F_1 (*barbadense* x *gossypioides*) is asynaptic and the simple genetic mechanism controlling this character has been dealt with in the chapter on Cytology. Menzel and Brown (1955) assumed the existence of duplicate factors, $\mathbf{a}_1$ and $\mathbf{a}_2$ responsible for reduction in chiasma frequency. They also as-

sumed that the genotypes for *arboreum* and *gossypioides* comprised $\mathbf{a_2}$ $\mathbf{a_2}$ and $\mathbf{a_1}$ $\mathbf{a_1}$ or similar genes and that the genotypes for the New World diploid species other than *gossypioides* possessed A_1 A_1 or similar genes. In complete dominance of A_1 together with the action of modifiers (polygenes) from *barbadense* in shifting the expression of $\mathbf{a_1}$ in the direction of greater dominance was suggested to be responsible for the extreme degree of asynapsis in the hybrid *barbadense-gossypioides* (genotype : A_1 $\mathbf{a_1}$ $\mathbf{a_2}$).

Thus the hybrids with *gossypioides* have uncovered differences between *thurberi* and *raimondii* on the one hand, and between *hirsutum* and *barbadense* on the other, which were not revealed by their respective F_1 hybrids. The block to further genetic analysis of *gossypioides* presented by its sterile F_1 hybrids can be circumvented by the fact that *thurberi-raimondii* and *hirsutum-barbadense* hybrids are fertile and can be crossed with *gossypioides*. Menzel and Brown (1955) have suggested that by proper manipulation of such three species hybrids it should be possible to gain some insight into the genetic basis of the various isolating mechanisms, and to obtain an estimate of the number of genes determining each character. It would be particularly interesting to determine whether the species differences discussed are due to a few loci with large effects (oligogenes), or to numerous loci each having individually a small effect (polygenes).

TABLE 75. GENE LIST FOR *Gossypium*

Symbol suggested	Original symbol if different	Gene effect	References	Species (+)
as_1		Double recessive is asynaptic	Beasley and Brown, 1942	*hirs.*
as_2			,, ,,	*barb.*
B_1		Blackarm resistance	Knight and Clouston, 1939, Knight, 1947b	*hirs.* (*barb.*)
B_2		Blackarm resistance	Knight and Clouston, 1939	*hirs.* (*barb.*)
B_3		Blackarm resistance	Knight, 1944b	*punct.** (*hirs.*) (*barb.*)
B_4		Blackarm resistance	Knight, 1948a,b	*arb.* (*barb.*)
B_5		Blackarm resistance	Knight, 1950	*barb.*
B_{6m}		Blackarm resistance intensifier	Knight, 1953b	*arb.* (*barb.*)
B_7		Blackarm resistance	Blank, 1949: Knight 1953a	*hirs.* (*barb.*)
b_8		Blackarm resistance	Knight, 1954a	*anom.* (*arb.*)
B_9		Blackarm resistance	Knight, 1956	*herb.*
Bp	B^P/B^S	Pitted boll	Smith, 1942	*barb.*
bw		Withering bracts	Knight, 1951	*hirs.*
chl_1	y_1 c^{ha}	Double recessive is chlorophyll deficient	Stroman and Mahoney, 1925	*hirs.*
chl_2	y_2 c^{hb}		Harland, 1932d, 1934b, Hutchinson, 1946a	*barb.*
chl_1		Chlorophyll deficient	Balasubrahmanyan, 1947: Ramanatha Ayyar and Balasubrahmanya Ayyar, 1938	*herb.*

TABLE 75. (*Contd.*)

Symbol suggested	Original symbol if different	Gene effect	References	Species (+)
chl_2		Chlorophyll deficient	Ramanatha Ayyar and Balasubramanya Ayyar, 1938; Hutchinson and Bholanath, 1938: Balasubrahmanyan 1947: Yu, 1939a	*arb.*
ck^x		Corky (complementary)	Stephens, 1950a	*hirs.*
ck^y				*barb.*
cl_1	**d**	Cluster	Thadani, 1923	*hirs.*
cl_2		Egyptian short branch	Silow, 1946	*barb.*
cl		Short branch	Patel, Munshi and Patel	*herb.*
clg		Cleistogamy	Neelakantan and Balasubrahmanyan, 1949	New World
Cr^B		Full normal; Distinguished only in hets. with **cr^D**	Harland, 1917: Harland and Atteck, 1941b: Hutchinson and Ghose, 1937c: Hutchinson, 1946b	*barb.*
Cr^H		Low normal; Distinguished only in hets. with **cr^D**		*hirs.*
cr^I		Rugose		*hirs.*
cr^D		Crinkled dwarf		*barb.*
cr^C		Contorta		*barb.*
Cp_a	**A**	Crumpled (complementary)	Hutchinson, 1932a,	*arb.*
Cp_b	**B**		Hutchinson, 1932a: Skovsted, 1935a	*arb. herb.* *stock. tril.*
cr		Crinkled	Harland, 1917: Hutchinson, 1946b	*barb. hirs.*
cr	**cra**	Crinkled	Balasubrahmanyan, and Santhanam, 1951b	*arb.*
cu		Curly	Yu, 1939b	Old World
d		Female-sterile dwarf	Khadilkar, 1946	*arb.*
d_1	**d_a**	Double recessive is dwarf-bunched	Knight, 1947b	*hirs.* (*barb.*)
d_2	**d_b**			*hirs.* (*barb.*)
d_1	**d_a**	Anakapalle dwarf	Balasubrahmanyan and Santhanam, 1950a	*arb.*
d_2	**d_b**	Cocanada dwarf	,, ,,	*arb.*
d_3	**Db**	Dwarf bushy	Venkoba Rao and Ramachandran, 1943	*herb.*
de_1	**de_a**	Incomplete boll dehiscence (**de_1** is epistatic to **de_2**)	Abraham, 1934: Balasubrahmanyan, Santhanam and Mayandi Pillai,1949	*herb.*
de_2	**de_b**			*arb.*
de_3		Closed boll	Kokuev, 1935	*herb.*
Fbr	**B^r**	Brown fuzz; Green epistatic to brown	Carver, 1929	*hirs.*
Fgr	**G**	Green fuzz; Green epistatic to brown		*hirs.*
Fm	**S^m**	Little fuzz	Kearney and Peebles, 1927	*barb.*
Fn	**Ab N 1**	Naked seed, low lint index	Thadani, 1923, 1925: Grifee and Ligon, 1929: Kearney and Harrison, 1927: Carver, 1929: Ware, 1929a, 1940: 1941a, b	*hirs.*

TABLE 75. (*Contd.*)

Symbol suggested	Original symbol if different	Gene effect	References	Species (+)
fr_1		Frilly (duplicate)	Hutchinson, 1946a	*hirs.*
fr_2				*hirs.*
Ft/Ft	T/t	Tufted seed/naked	Harland, 1929a	*barb.*
Fz/fz	F^t/f^t	Tufted seed/fuzzy	Carver, 1929	*hirs*
Fz/fz	T/t	Tufted seed/fuzzy	Hutchinson, 1935	*arb.*
g		No ovary	Balasubrahmanyan, 1950b	Old World
H_1	H^{TA} H^B	Hairy leaves	Harland, 1944: Knight, 1952, 1954d	*barb. hirs. herb.*
H_2	H^{TO}	Tomentose leaves	Harland, 1939: Simpson, 1947 Knight, 1952: Knight and Sadd, 1953	*tom. hirs. (barb.)*
H^{st}		Super stellate hairs	Ramiah and Paranjpe, 1944	*herb.*
h_a	h^G	Glabrous-lintless	Kottur, 1927: Afzal and Hutchinson, 1933: Hutchinson and Gadkari, 1937	*arb.*
h_b		Glabrous-lintless	Afzal and Hutchinson, 1933: Hutchinson and Gadkari, 1937	*arb.*
l		Broad leaf	Silow, 1939a: Balasubrahmanyan, 1951	*arb. herb.*
L		Narrow leaves	Hutchinson, 1934: Silow 1939a: Balasubrahmanyan, 1951	*arb.*
L^A		*anomalum* lobe	Silow, 1939a	*anom.*
L^B		Mutant broad leaves	Hutchinson, 1934: Silow, 1939a	*arb.*
L^I		Mutant inter. leaves	,, ,,	*arb.*
L^L		Liciniate leaves	,, ,,	*arb.*
L^N		Narrow leaves	,, ,,	*arb.*
L^O	O^O/o^n	Okra-leaf	Shoemaker 1908: Harland, 1932c	*hirs.*
L^S	O^S/o^n	Super okra	,,	*hirs*
Lc_1^K	K^H	Khaki lint	Harland, 1935b: Hutchinson, 1946c	*hirs.*
Lc_1^K	K_1 K	Khaki lint	Balasubrahmanyan, Mudaliar and Santhanam, 1950: Ramanathan and Balasubrahmanyan, 1933b: Hutchinson, 1934	Old World
Lc_1^M		Cauca mahogany lint	Hutchinson *et al.*, 1950	New World
lc_2	k_2	White lint	Balasubrahmanyan, Mudaliar and Santhanam, 1950: Ramanathan and Balasubrahmanyan, 1933b: Silow, 1944b	Old World
Lc_2^B	D_1	Light brown lint	Balasubrahmanyan *et al.*, 1950; Silow, 1944b; Hutchinson, 1935	Old World
Lc_2^K	K^B	Khaki lint	Harland, 1935b	*barb.*
Lc_2^K	K_2	Khaki lint	Balasubrahmanyan *et al.*, 1950 Ramanathan and Balasubrahmanyan 1933b; Silow, 1944b	Old World

TABLE 75. (*Contd.*)

Symbol suggested	Original symbol if different	Gene effect	References	Species (+)
Lc_2^M		Medium brown lint	Silow, 1944b	Old World
Lc_2^V		Very light brown lint	Balasubrahmanyan *et al.*, 1950: Silow, 1945	Old World
Lc_3^B	D_2	Light brown lint	Hutchinson, 1935: Silow, 1944b	Old World
Lc_4^K		Khaki lint	Silow, 1945	*arb.*
Lg	G_1	Green lint	Harland, 1929b	New World
li_a		Hairy-lintless	Hutchinson and Gadkari, 1937: Govande, 1944a	*herb.*
li_b		Hairy-lintless	Hutchinson and Gadkari, 1937	*herb.*
li_c	H^L	Hairy-lintless (sometimes lethal)	Afzal and Hutchinson 1933: Hutchinson and Gadkari, 1937	*arb.*
li_d		Hairy-lintless	Govande, 1944b	*herb.*
li_e		Hairy-lintless	Balasubrahmanyan and Santhanam, 1952	*arb.*
li_{sh}		Short lint (epistatic to li_e)	,, ,,	*arb.*
li_{sp}		Sparse lint	Balasubrahmanyan and Santhanam, 1950b	*arb.*
lm		Immature lint	Balasubrahmanyan *et al.*, 1949	*arb.*
lr	r^1	Round-leaf	Brown and Cotton, 1937: Richmond and Harper, 1937	*hirs.*
ls	s	Single-lobed leaf	Ramiah and Bholanath, 1943	*arb.*
m_1	m	Increased no. of floral parts	Ramanathan and Balasubrahmanyan, 1938: Balasubrahmanyan, 1950b	*arb.*
m_2	m^b	Multibracteolate	Govande, 1946	*herb.*
ne		Leaf nectaries absent	Stephens, (Unpubl.)	*tom.* (*hirs.*)
ne		Leaf nectaries absent	Leake, 1911a	Old World
p_a		Pollen colour: P_a P_b yellow,	Ramanathan and Balasubrahmanyan, 1933a: Silow, 1941	Old World
p_b		p_a P_b cream, P_a p_b pale		Old World
Pdy	Fpd	Petalody	Balasubrahmanyan, 1950b: Ramanathan and Sankaran, 1934: Hutchinson and Ghose, 1937d: Afzal and Singh, 1939:	*arb.*
pte		Pistillate	Balasubrahmanyan and Santhanam, 1951a	Old World
R_1^{RO}	R^H R^1	Red plant body	McLendon, 1912: Thadani, 1923: Ware, 1927, 1929b: Carver, 1929: Harland, 1932 b, c, Neely, 1942	New World
R_1^{ARM}	S^{ARM}	*arm.* petal spot	Harland and Atteck, 1941a	*arm.* (*hirs.*) (*barb.*)
R_1^{ARI}	S^{ARI}	*arid.* petal spot	,,	*arid.* (*hirs.*) (*barb.*)
R_2^{AF}	S^f	Tinged stem+full petal spot	Harland, 1929b, c	*barb.*
R_2^{AL}	S^i	Tinged stem+intermediate spot	,,	*barb.*

TABLE 75. (*Contd.*)

Symbol suggested	Original symbol if different	Gene effect	References	Species (+)
R_2^{AO}	S^o	Tinged stem, spotless	Harland, 1929b, c	*hirs.*
R_2^{ASB}	S^s R_2^{AS}	Tinged stem + full spot	,,	*barb.*
R_2^{ASA}	R_2^{AS}	Sun-red, spotted	Balasubrahmanyan *et al.*, 1949: Ramiah, 1945	*arb.*
R_2^{BO}		Sun-red, spotless	,,	*arb.*
R_2^{CS}	R^C	Red calyx, spotted	,,	*herb.*
R_2^{DS}		Thumb-nail red, spotted	,,	*arb.*
R_2^{DO}	R_2^{EO}	Thumb-nail red, spotless	,,	*herb.*
R_2^{FO}		Green stem, spotless, tinged petal	,,	*arb.*
R_2^{GS}		Weak thumb-nail red, spotted	Ramiah and Bholanath, 1944: Ramiah, 1945	*arb.*
R_2^{HO}		Green stem spotless, petal untinged	Balasubrahmanyan, *et al.*, 1949: Ramiah and Bholanath, 1944; Ramiah, 1945	*arb.*
R_2^{LO}	R_2^{O}	Red leaf, spotless	Hutchinson and Ghose, 1937c	Old World
R_2^{LS}	R^L	Red leaf, spotted	Ramiah, 1945	*herb.*
R_2^{LW}	R_2, S^W, S^C	Red leaf, spotted	Kearney, 1924: Harland, 1929b, c; 1932c	*barb. purp.**
R_2^{MS}		Red margin, spotted	Balasubrahmanyan *et al.*, 1949: Ramiah, 1945	*arb.*
R_2^{MO}	R_2^{NO}	Red margin, spotless	Silow and Yu, 1942	*arb.*
R_2^{OS}	r^g	Green stem, ghost spot	Balasubrahmanyan *et al.*, 1949: Silow, 1941: Silow and Yu, 1942: Ramiah, 1945	*arb. herb. anom.*
R_2^{RS}	R	Full red, spotted	Hutchinson, 1932b: Harland, 1935a: Knight, 1945	*arb.* (*hirs.*) (*barb.*)
R_2^{TS}		Green stem, tinged ghost spot	Ramiah, 1945	*arb.*
R_2^{VS}		Red vein, spotted	,,	*arb.*
R_2^{VO}	R_2^{WO}	Red vein, spotless	Balasubrahmanyan *et al.*, 1949: Ramiah, 1945	*arb.*
R_3^{GO}		Gold petel spotless	Silow, 1941	*anom.*
r_3^{OO}		Green, spotless	,,	*arb.* (*herb.*)
Rd		Red dwarf	McMichael, 1942: Johnson, 1949	*hirs.*
Rl_a		Red lethal, complementary with factor(s) from Upland	Gerstel, 1953, 1954	*arb.*
sh	s^h	Short sympodia	Kearney, 1930b	*barb.*
Sr		Spot reducer	Hutchinson and Ghose, 1937c	*arb.*
stg		Female sterile	Stroman, 1941	*hirs.*
stg		Female sterile	Balasubrahmanyan, 1950b: Vijayaraghavan *et al.*, 1936	*herb.*
stp		Male sterile	Hutchinson and Gadkari, 1935	Old World
v_1	v_a	Virescent a	Yang, 1945	*hirs.*
v_1		Virescent yellow	Yu, 1939b, 1941	Old World

TABLE 75. (*Contd.*)

Symbol suggested	Original symbol if different	Gene effect	References	Species (+)
v_2	v^c	Virescent c	Yang, 1945	*hirs.*
v_2		Virescent yellow	Yu, 1941	Old World
v_3	v_f	Virescent f	Yang, 1945	*hirs.*
v_3		Virescent yellow	Yu, 1941	Old World
v_4	$v\ v_k$	Virescent k	Killough and Horlacher 1933: Yang, 1945	*hirs.*
v_4		Virescent yellow	Yu, 1941	Old World
v_5	v_1	Virescent 1	Yang, 1945	*hirs.*
vc		5 loculed bolls	Anonymous, 1945: Ramiah and Bholanath, 1947	*arb.*
W_1	A	*Fusarium* resistance	Kelkar *et al.*, 1947c	*arb. herb.*
W_2	B	*Fusarium* resistance	,,	*arb. herb.*
W_3	C	*Fusarium* resistance inhibitor	,,	*arb. herb.*
X		Lint colour modifier	Ramanathan and Balasubrahmanyan, 1933a	*arb. herb.*
Y_1	Y^B	Yellow corolla	Harland, 1920: Stephens, 1954	*barb.*
Y_1^P	y	Cream corolla	Hutchinson and Silow, 1939: Stephens, 1954	New World
Y_2	Y^D	Yellow corolla	Harland, 1936c	*darwinii**
Y_a	Y	Yellow petal	Hutchinson, 1931: Silow, 1941: Bholanath, 1942	*arb., herb.*
Y_a^P	Y_p	Pale petal	Leake, 1911a; Hutchinson, 1931: Silow, 1941	Old World
y_a	y	White petal	Hutchinson, 1931	Old World
Y_b		Chinese yellow petal	Silow, 1941: Bholanath, 1942	Old World
Y_b^P		Chinese pale petal	Silow, 1941	Old World
Y_c		Yellow petal	,,	*anom.*
Y_c^P		Pale petal	,,	*anom.*
Ydp		Yellow depressor	,,	*anom.*

(+) The use of brackets in this column indicates species to which the gene concerned has been transferred from its original species by hybridization.

Note:—Multiple alleles are shown by series of alphabetic superscripts. Duplicate factors are shown by numerial subscripts. Complementary factors are shown by alphabetic subscripts. Genes in Old World species are italicized. Those in New World species are given the same symbols but are not italicized unless they are known to be located in the A genom or unless homology of the locus with the Old World locus is proved.

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Note : I.C.C.C. = Indian Central Cotton Committee.

I.C.G.R. = Indian Cotton Growing Review.

P. B. A. = Plant Breeding Abstracts.
(Commonwealth Bureau of Agriculture).

APPENDIX I

CONSTITUTION OF THE INDIAN CENTRAL COTTON COMMITTEE

1. President: Vice-President, Indian Council of Agricultural Research (*ex-officio*).
2. Agricultural Commissioner with the Government of India (*ex-officio*).
3. Nine representatives of Agriculture Departments of Madras, Bombay, Uttar Pradesh, Madhya Pradesh, the Punjab, Mysore, Assam, Rajasthan and Kerala States.
4. Director General of Commercial Intelligence and Statistics (*ex-officio*).
5. Eight representatives of Chambers of Commerce and Associations from:

    The East Indian Cotton Association,

    The Bombay Millowners' Association,

    The Bombay Chamber of Commerce,

    The Indian Merchants' Chamber,

    The Ahmedabad Millowners' Association,

    The Tuticorin Chamber of Commerce,

    The Upper India Chamber of Commerce, and

    The Empire Cotton Growing Corporation.
6. Four representatives of the Cotton Manufacturing or Cotton Ginning Industry—two from Madhya Pradesh, one each from Madras and the Punjab States.
7. One person nominated by the Central Government to represent West Bengal.
8. One representative of Co-operative Banking nominated by the Central Government.
9. Twelve representatives of Cotton Growing Industry nominated by the Central Government—two each from the States of Madras, Bombay, Uttar Pradesh, Madhya Pradesh and one each from the Punjab, Andhra Pradesh, Mysore and Rajasthan.
10. Such additional members as nominated by the Central Government (14 at present).

APPENDIX II

LIST OF IMPROVED VARIETIES OF COTTON EVOLVED UNDER THE RESEARCH SCHEMES OF THE INDIAN CENTRAL COTTON COMMITTEE

1. *Thirty varieties in Bombay*, viz., B.D.8, Vijay, Digvijay, Wagad 8, Wagotar, Kalyan, Jarila, Virnar, Y.1, Pratap, C.J.73, 170-Co.2, 134-Co.2-M, Suyog,* Vijalpa,* Gaorani 6, Gaorani 12, Daulat, Parbhani-American 1, 1585, 1422, Raichur 19, H.A.11, H.420, Buri 107, Buri 0394, V.262, V.434, Malini and No. 91.

2. *Sixteen varieties in Madras*, viz., Co.1,* Co.2,* Co.3,* Co.4,* 4466,* 920,* M.C.U. 1,* M.C.U. 2, 9030, 9030G, 0734, C.7,* K.1,* K.2,* K.5 and 6186-9.

3. *Nine varieties in Madhya Pradesh*, viz., Malvi 9, Malvi 10, Malvi 12, C. Indore 1, Indore 2, Bhoj, Nimar 1, Nimar 2 and Maljari.

4. *Eight varieties in Mysore*, viz., M.A.2, M.A.5, Sel. 69, Gadag 1,* D.1,* Laxmi,* Jayawant* and Jayadhar.*

5. *Eight varieties in Andhra Pradesh*, viz., Rayalaseema 1, 2196-4, 1821-1-1, C.1, C.2, N.14, H.1 and H. 25.

6. *Seven varieties in the Punjab*, viz., 216F, 320F, Rosea 231, H.14, LL.53, LL.54 and J.34.

7. *Four varieties in Uttar Pradesh*, viz., C.520, C.402, 35/1 and Perso-American.

8. *Three varieties in Rajasthan*, viz., M.49-398, Ganganagar 1 and M.48-4.

9. *One variety in Kerala*, viz., 'Andrews' (acclimatised West Indies Sea Island).

10. *One variety in Assam*, viz., D.46-2-1.

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*Evolved by State Agriculture Departments.

APPENDIX III

INDIAN COTTON TEXTILE INDUSTRY

The cotton textile industry in India is the second largest in the world, next only to that of the U.S.A. in size and productive capacity. It provides one of the primary necessities of life to millions of people in India, which has the second largest population in the world. Besides, it enables the country to export annually over 800 million yards of cloth enabling the country to be the second largest exporter of cotton textiles. With one-third of the total capital invested, absorbing over one-third of the employees and clearing 50 per cent. of the payments to them by way of wages, salaries and benefits, it ranks foremost among the factory industries of India with an important say in the economy of the country. This industry is the mainstay of the cotton grower, the handloom weaver and the vast number of individuals engaged in the cotton, yarn and cloth trades and in the manufacture of textile auxiliaries. In fact, the industry touches the economic life of the community at so many points that it is impossible to assess the actual number of persons dependent on it.

Tracing the early history, one can find that Indian made cloth was known even before 3,000 B.C. and exported to Western countries. With the advent of the British rule in India, the Lancashire machines usurped the place of the deft Indian hands. In 1817, the first British owned mill was started in Calcutta, followed by an Indian enterprise in Bombay, in 1854. Mills sprung up steadily thereafter and by the end of the 19th century, there were 193 mills with a total spindleage of 49,45,783 and 40,124 looms. At the earlier stages of the industry the accent was on the spinning of yarn, which had an assured market both at home and abroad. For instance, in 1902, with an export of 121 million lbs. of yarn, India was the second biggest exporter of yarn to China. Owing to the keen competition from Japan, India lost its ground, and on the advent of the First World War, there was a significant decline in the volume of the yarn exports. Thus, the stage was set for the virtual integration of the industry by expanding its weaving section, for absorbing the surplus yarn output, as a result of which, during the period from 1899 to 1922, the number of looms and spindles in the mills increased by 223 per cent. and 50 per cent., respectively. Although the production of cloth and yarn increased steadily during the subsequent years, the impact of Japanese and British competitions on the home market and the great depression in the 30's had undermined the stability of many mills. But the Second World War helped considerably the industry to grow in strength and vigour. India's powerful competitors were compelled to curtail their textile production and suspend their export activities during the War. The progress due to this favourable turn for the industry was, however, arrested by the partition of the country in 1947, which affected immensely the supply of essential raw material. The industry was also deprived of an assured outlet for its products amounting to 800 to 900 million yards of cloth annually. Nevertheless, the industry succeeded in surviving these economic upheavals due to the timely action taken by the Government and today it holds a position of great importance in the national economy. With 465 cotton textile mills, India now holds the third place, next only to the U.S.A. and the United Kingdom in spindleage and is the world's second largest producer of cotton textiles. Scarcely five decades ago, India was one of the world's largest importers of textiles; the import from the United Kingdom alone amounting to more than 2,560 million yards in 1913. The position has now reversed and today India is one of the leading exporters of piecegoods. Indian exports are finding their way not only to countries in the Middle and Near East and Africa, but also to the United Kingdom. The progress made by the industry since 1900 to-date can be viewed from the following statement which shows the number of mills, spindles and looms installed and the production of yarn and cloth registered during different periods.

PROGRESS OF THE INDIAN TEXTILE INDUSTRY

Year		Number of mills	Number of spindles	Number of looms	Production of yarn (million lb.)	Production of cloth (million yards)
1900	..	193	4,946,000	40,000	Not available	
1910	..	263	6,196,000	83,000		
1920	..	253	6,763,000	119,000		
1930	..	348	9,125,000	179,000	867*	2,561*
1940	..	388	10,006,000	200,000	1,349*	4,269*
1950	..	425	10,849,000	200,000	1,174	3,666
1956	..	465	12,376,000	207,000	1,671	5,307

*Figures relate to the year ending the 31st March of the succeeding year, figures for calendar year being not available.

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ERRATA

Page viii, line 7. *For* Southern *hirsutum* Region
Read Southern *hirsutum-arboreum* Region

Page 1, line 28. *For* Northern *hirsutum* Region
Read Northern *hirsutum-arboreum* Region